

# Marine Nuclear Power: 1939 – 2018

## Part 1: Introduction

Peter Lobner  
July 2018

# Foreword

In 2015, I compiled the first edition of this resource document to support a presentation I made in August 2015 to The Lyncean Group of San Diego ([www.lynceans.org](http://www.lynceans.org)) commemorating the 60<sup>th</sup> anniversary of the world's first "underway on nuclear power" by *USS Nautilus* on 17 January 1955. That presentation to the Lyncean Group, "60 years of Marine Nuclear Power: 1955 - 2015," was my attempt to tell a complex story, starting from the early origins of the US Navy's interest in marine nuclear propulsion in 1939, resetting the clock on 17 January 1955 with *USS Nautilus*' historic first voyage, and then tracing the development and exploitation of marine nuclear power over the next 60 years in a remarkable variety of military and civilian vessels created by eight nations.

In July 2018, I finished a complete update of the resource document and changed the title to, "Marine Nuclear Power: 1939 - 2018." What you have here is *Part 1: Introduction*. The other parts are:

- *Part 2A: United States - Submarines*
- *Part 2B: United States - Surface Ships*
- *Part 3A: Russia - Submarines*
- *Part 3B: Russia - Surface Ships & Non-propulsion Marine Nuclear Applications*
- *Part 4: Europe & Canada*
- *Part 5: China, India, Japan and Other Nations*
- *Part 6: Arctic Operations*

# Foreword

This resource document was compiled from unclassified, open sources in the public domain. I acknowledge the great amount of work done by others who have published material in print or posted information on the internet pertaining to international marine nuclear propulsion programs, naval and civilian nuclear powered vessels, naval weapons systems, and other marine nuclear applications. My resource document contains a great deal of graphics from many sources. Throughout the document, I have identified all of the sources for these graphics.

If you have any comments or wish to identify errors in this document, please send me an e-mail to: [PL31416@cox.net](mailto:PL31416@cox.net).

I hope you find this informative, useful, and different from any other single document on this subject.

Best regards,

Peter Lobner  
July 2018

# Marine Nuclear Power: 1939 – 2018

## Part 1: Introduction

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Quick look:  
then and now

# 17 Jan 1955: *USS Nautilus* (SSN-571) made the first voyage of a nuclear-powered vessel

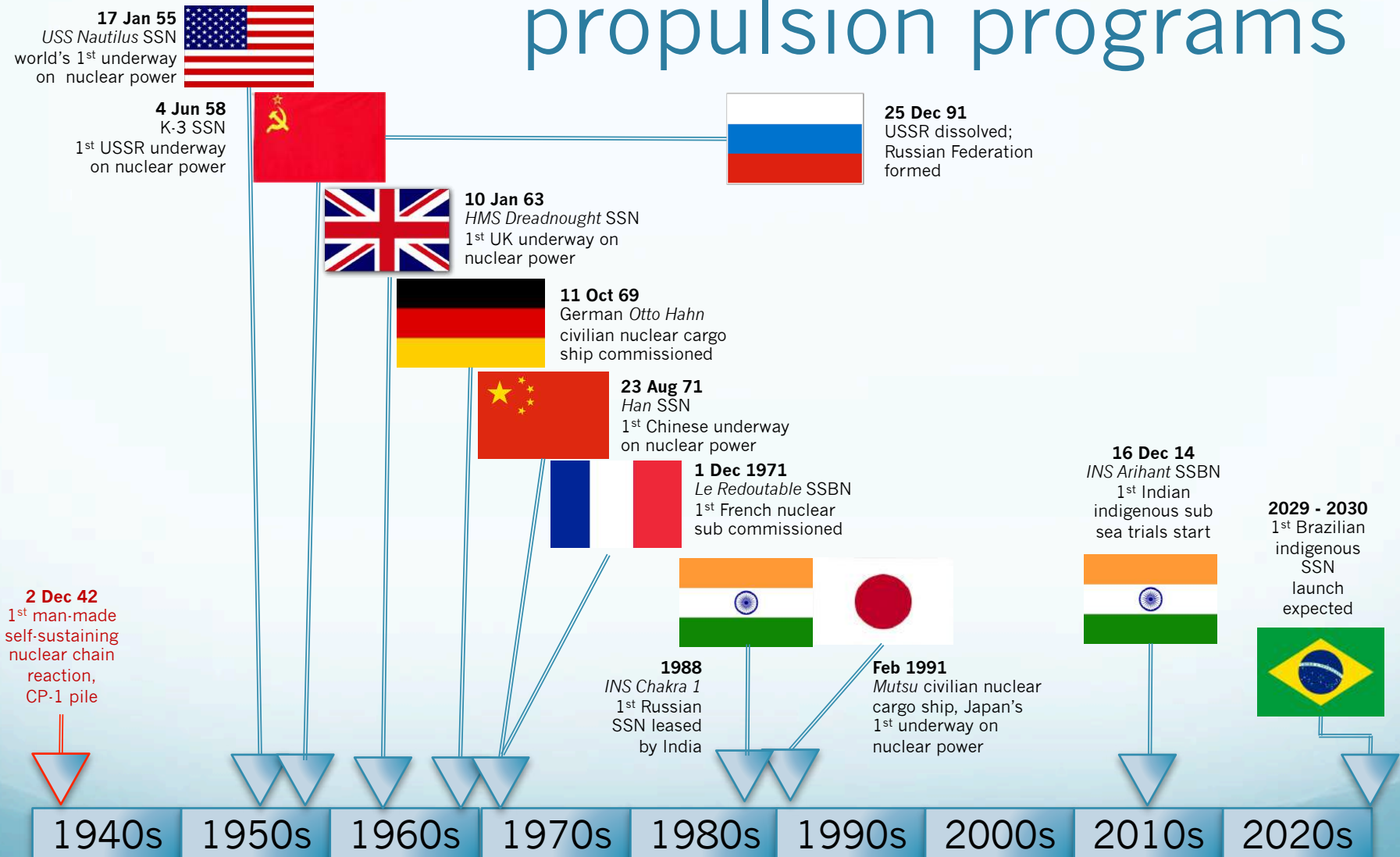
- Capt. Eugene P. Wilkinson was the commanding officer of *Nautilus* on that historic voyage, which was made from the US Navy submarine base at Groton, CT.
- The famous message, “UNDERWAY ON NUCLEAR POWER,” was sent by flashing light signal to Commander Submarine Forces Atlantic.
- *Nautilus* was built by Electric Boat (a division of General Dynamics), Groton, CT.
- The reactor was a 70 MWt S2W pressurized water reactor (PWR) built by Westinghouse Electric Company.
- This was the start of a revolution in marine propulsion and naval technology that is continuing today.



Capt. Eugene P. Wilkinson & *Nautilus*

Source: US Navy

# Timeline of marine nuclear propulsion programs



# The world's marine nuclear fleets

Types of nuclear vessels and other marine nuclear applications

| NAVAL NUCLEAR-POWERED VESSELS           | USA      | Russia             | UK | France | Germany   | Japan | China | India | Other  |
|---|----------|--------------------|----|--------|-----------|-------|-------|-------|--------|
| Submarine                               |          |                    |    |        |           |       |       |       | Brazil |
| Aircraft carrier                        |          | Ulyanovsk          |    |        |           |       |       |       |        |
| Cruiser                                 |          |                    |    |        |           |       |       |       |        |
| Destroyer                               |          | Leader-class       |    |        |           |       |       |       |        |
| Other naval vessel                      |          | SSV-33             |    |        |           |       |       |       |        |
| CIVILIAN NUCLEAR POWERED VESSELS        |          |                    |    |        |           |       |       |       |        |
| Icebreaker                              |          |                    |    |        |           |       |       |       |        |
| Merchant ship                           | Savannah |                    |    |        | Otto Hahn | Mutsu |       |       |        |
| Floating nuclear power plant            | Sturgis  | Akademik Lomonosov |    |        |           |       |       |       |        |
| OTHER MARINE NUCLEAR POWER APPLICATIONS |          |                    |    |        |           |       |       |       |        |
| Marine RTG power sources                |          |                    |    |        |           |       |       |       |        |







Legend:

|  |  |
|--|--|
|  | Currently operating this class of nuclear-powered vessel or RTG                              |
|  | Previously operated this class of nuclear-powered vessel                                     |
|  | Previously started construction on this class of nuclear-powered vessel but did not complete |
|  | Expected to operate this class of nuclear-powered vessel within the next decade              |



# The world's marine nuclear fleets

Estimated total of 175 operating nuclear-powered vessels as of mid-2018

|   | Nuclear submarines |                              |                           |                        | Nuclear surface ships    |                          | Country totals |
|---|--------------------|------------------------------|---------------------------|------------------------|--------------------------|--------------------------|----------------|
|   | Attack sub (SSN)   | Strategic missile sub (SSBN) | Cruise missile sub (SSGN) | Other special nuc subs | Naval surface combatants | Civilian surface vessels |                |
|    | 50                 | 14                           | 4                         | 0                      | 11 CVN                   | 0                        | 79             |
|    | 18                 | 11                           | 8                         | 9 Spec-op              | 1 CGN                    | 5                        | 52             |
|    | 6                  | 4                            | 0                         | 0                      | 0                        | 0                        | 10             |
|    | 14                 | 6                            | 0                         | 0                      | 0                        | 0                        | 20             |
|   | 6                  | 4                            | 0                         | 0                      | 1 CVN                    | 0                        | 11             |
|  | 1 (leased)         | 2                            | 0                         | 0                      | 0                        | 0                        | 3              |

CVN = Nuclear-powered aircraft carrier; CGN = Nuclear-powered guided missile cruiser  
 MTS = Moored Training Ship (non-operational)

# State-of-the-art in 1955

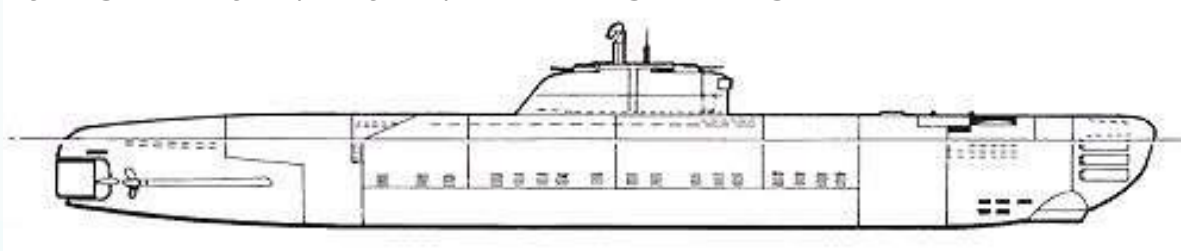
# State-of-the-art in 1955

- Submarine hull design
- Submarine propeller (propulsor) design
- Surface ship design & weaponry
- Submarine weaponry
- Nuclear weapons
- Thermonuclear weapons
- Communications
- Navigation
- Shipboard computers

# State-of-the-art in 1955

## Submarine hull design

- WW II German Type XXI “Elektroboat” set the standard for post-war hydrodynamic hull design and underwater performance
  - Faster speed submerged (17.2 kts) than when running on the surface (15.7 kts)
  - Very large battery capacity; capable of long submerged endurance



German Type XXI  
Source: [www.uboataces.com](http://www.uboataces.com)

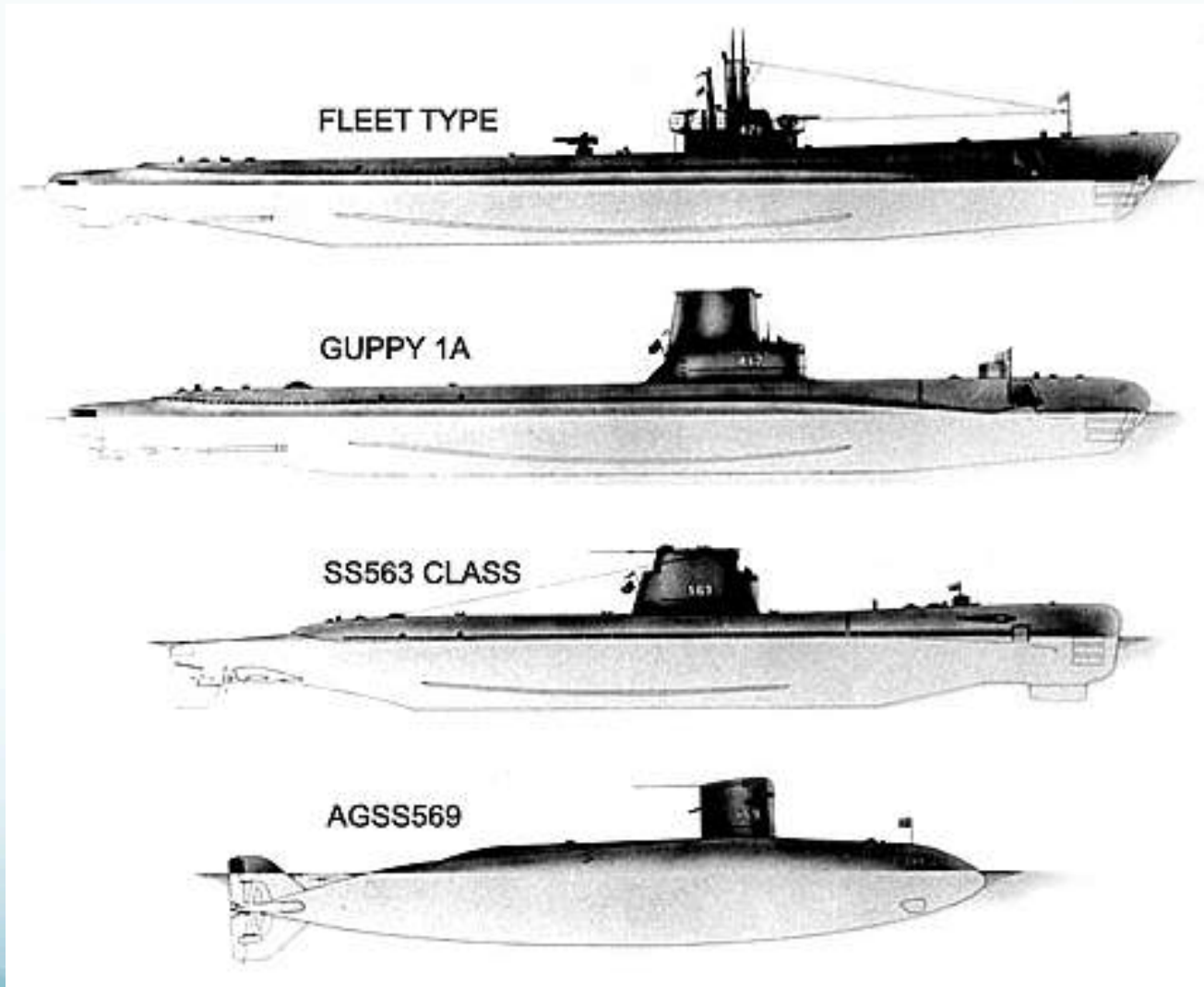
- US Navy implemented the Greater Underwater Propulsion Power Program (GUPPY) program to improve WW II-era diesel submarines.
  - Key GUPPY features included removing the deck guns, streamlining the outer hull, replacing the conning tower with a sail, installing new propellers optimized for submerged operations, installing a snorkel mast and more air conditioning, and doubling the battery capacity.
  - *USS Tang* (SS-563) and *USS Darter* (SS-576) were the first post-war US conventional submarines designed under the GUPPY program. *Tang* was commissioned in October 1951, and *Darter* in October 1956.
  - Their cleaner hull form is similar to the early US nuclear submarines: *Nautilus*, *Seawolf* and the four-boat Skate-class.



*USS Darter*  
Source: [www.shipbucket.com](http://www.shipbucket.com)

# State-of-the-art in 1955

Evolution of US post-war diesel sub hull design



Source: adapted from [ussalbacore.org](http://ussalbacore.org)

# USS Albacore (AGSS-569)

Revolutionary hull design



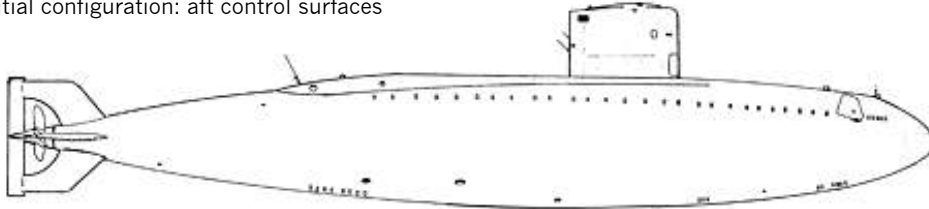
Source: [www.princeton.edu](http://www.princeton.edu)

| Class    | # in Class | Length           | Beam           | Displacement (tons)     | Engine  | Shaft hp | Max speed | Years delivered | Years in service |
|----------|------------|------------------|----------------|-------------------------|---|----------|-----------|-----------------|------------------|
| Albacore | 1          | 62.1 m (204 ft.) | 8.2 m (27 ft.) | 1240 (surf), 1540 (sub) | 2 x GM 16-338 pancake diesels, 1 x electric motor | 7,500    | 33 kts    | Dec 1953        | Dec 53 – Dec 72  |

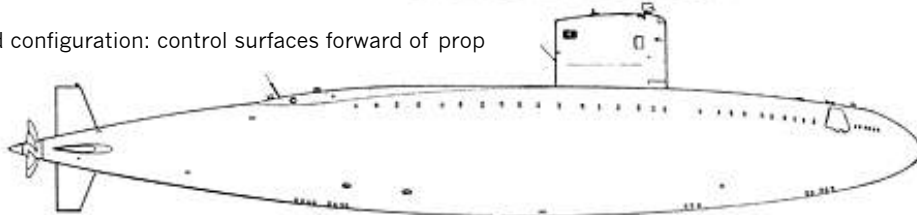
- *Albacore's* advanced hull form was the result of a 1949 study by US Navy Bureau of Ships (BuShips) and subsequent tests conducted by David Taylor Model Basin, Carderock, MD.
- Key characteristics: teardrop-shaped hull & single screw, which were incorporated immediately into the Skipjack-class SSN and all subsequent classes of US nuclear subs. Also introduced HY-80 high-strength steel hull, which was the US standard through the Los Angeles-class SSN.
- Construction authorized Nov 1950; built at Portsmouth Naval Shipyard; launched in Aug 1953.
- Tested various control surface and propeller configurations, including dorsal rudder on the sail, X-configured stern planes, contra-rotating propellers, and deployable speed brakes.

# USS Albacore (AGSS-568)

Initial configuration: aft control surfaces



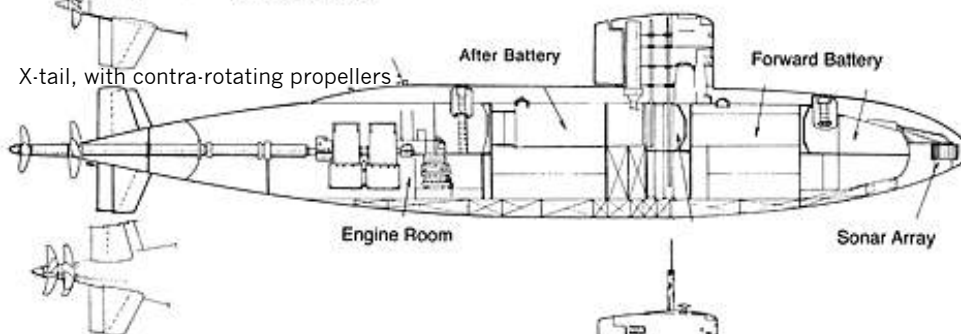
2nd configuration: control surfaces forward of prop



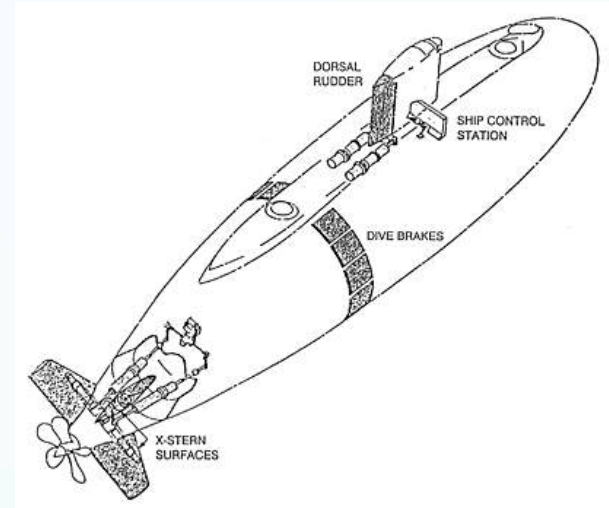
X-tail



X-tail, with contra-rotating propellers



X-tail, with moderate separation between contra-props



Above: X-tail, dorsal rudder & "dive brakes"

Below: Final X-tail & contra-rotating prop configuration



Source: all three graphics from [www.ussalbacore.org](http://www.ussalbacore.org)



# State-of-the-art in 1955

## Submarine propeller (propulsor) design

- During WWII, US fleet-type diesel submarines had two screws, typically with broad, 4-bladed symmetrical propellers. These were retained in some post-war GUPPY modified subs and were original equipment on the post-war Tang-class diesel subs.
- Improved 5-bladed diesel submarine propellers were introduced after WWII, and were retro-fit on the Tang-class diesel submarines and some GUPPY modified subs.
- Some of the early US nuclear subs originally had 4-bladed props (twin-screw Skate-class & *Halibut*), while others originally had 5-bladed props (twin-screw *Nautilus* and the single-screw Skipjack-class SSNs, *USS Tullibee*, and early Polaris SSBNs).



Diesel sub *USS Cod* (SS-224) propeller.  
Source: <https://imgur.com/a/IQBOiUSS>



*USS Nautilus* (SSN-571) propeller.  
Source: <https://imgur.com/a/IQBOi>



# State-of-the-art in 1955

## Submarine propeller (propulsor) design

- Larger, more advanced propellers with seven “skewback” (scimitar-shaped) blades were introduced in the early-1960s on the Permit-class SSNs and became the norm on US subs thereafter. These blades delayed cavitation, thereby reducing the noise generated by the propeller. These advanced propellers were retro-fit onto earlier nuclear subs.
- Pump-jet propulsors would not appear until the 1970s, first on the UK SSN *HMS Churchill* and then on all following UK nuclear subs. The US adopted pump-jet propulsors on Seawolf-class SSNs (1997) and Virginia-class SSNs (2004).

Five-bladed propeller on US SSN *USS Tullibee* (SSN-597). This was also original equipment of Skipjack-class SSNs and early Polaris SSBNs.



Source: Marco Brigandi

Seven-bladed propeller on French SSBN museum ship *Le Redoutable* (S611) at Cite de la Mere. This design is similar to the advanced propellers introduced on Permit-class SSNs.



Source: <https://i.imgur.com/80NGOTq.jpg>

# State-of-the-art in 1955

## Surface ship design & weaponry

- *USS Forrestal* (CV-59) was commissioned on 1 October 1955.
  - This was the first modern aircraft carrier design. It embodied all of the major design features carried forward into later US conventional aircraft carriers and the nuclear-powered *USS Enterprise* (CVN-65) and Nimitz-class.
- No US nuclear-powered surface ships were under construction in 1955.
- Anti-aircraft missiles were just beginning to be introduced to the surface fleet in the mid-1950s as modifications to WW-II ships.
  - First test launch of a Terrier (SAM-N-7, later RIM-2) from a ship occurred on 28 January 1953 from the battleship *USS Mississippi* (BB-41).
  - First ship to reach operational status with the Terrier anti-aircraft missile was the Baltimore-class cruiser *USS Canberra* (CA-70 / CAG-2), when it was re-commissioned on 15 June 1956.
- 1<sup>st</sup>-generation surface ship-launched land-attack Regulus I cruise missiles were deployed on the modified Baltimore-class cruiser *USS Los Angeles* in 1955, and three more cruisers in 1956. Ten aircraft carriers were configured to carry and launch Regulus I and to employ their jet aircraft to provide mid-course guidance to Regulus I missiles launched from other ships.



*USS Forrestal* sea trials September 1955.  
Source: US Navy



*USS Los Angeles* launches Regulus I in 1957.  
Source: US Navy / Wikipedia

# State-of-the-art in 1955

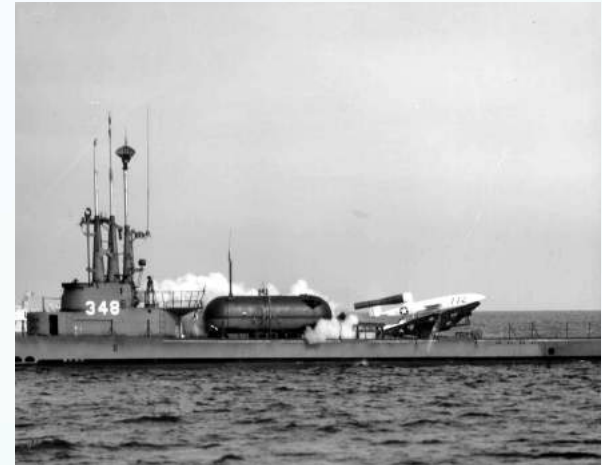
## Submarine weaponry – torpedoes, mines & guns

- Various WW II-era torpedoes
  - Mk 14, 21" (533 mm) straight-running torpedo
    - Methanol fuel, 643 lb. (292 kg) warhead, range: 4,500 yards (4.1 km) @ 46 kts; 9,000 yards @ 31 kts
    - Service dates: 1931 – 1980
  - Mk 16, 21" (533 mm) straight or pattern-running torpedo
    - Concentrated hydrogen peroxide (Navol) fuel, 746 lb. (338 kg) warhead, range: 11,000 – 13,700 yards (10.1 -12.5 km) @ 46 kts
    - Service dates: 1946 – 1975
  - Mk 27 Mod 4, 19" (483 mm) passive acoustic homing torpedo
    - Electric, 585 lb. (265 kg) warhead, range: 4,000 yards (3.7 km) @ 19.6 kts
    - Service dates: 1946 – 1960
  - Mk 28 21" 21" (533 mm) passive acoustic homing torpedo
    - Electric, 128 lb. (58 kg) warhead, range: 6,200 yards (5.7 km) @ 15.9 kts
    - Service dates: 1944 – 1960
- Various WW II-era mines
- No deck guns
  - All removed in an effort to streamline older submarines under the Navy's GUPPY program.

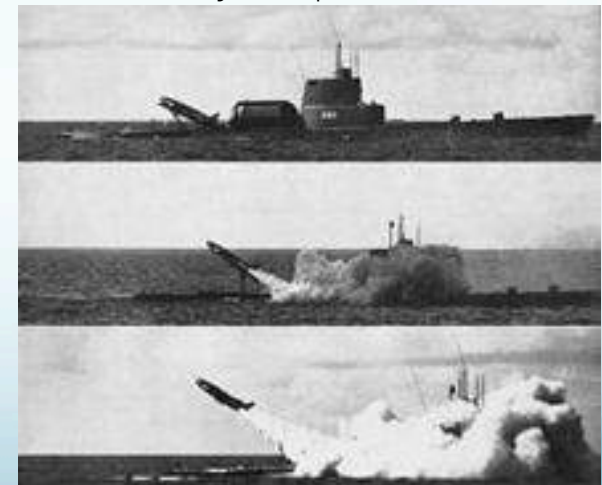
# State-of-the-art in 1955

## Submarine weaponry – cruise missiles & ballistic missiles

- 1<sup>st</sup>-generation submarine-launched land-attack cruise missiles were under development.
  - 12 February 1947: First JB-2 Loon missile tested from a submarine, *USS Cusk* (SS-348)
  - July 1953: First Regulus I launched from a submarine, *USS Tunny* (SS-282)
- Submarine-launched ballistic missile development was just starting.
  - 9 September 1955: Joint program established to develop the Army's liquid-fueled Jupiter intermediate range ballistic missile (IRBM) for Navy use on submarines & surface ships.
- No anti-ship cruise missiles in 1955.
- Submarines did not carry nuclear weapons in 1955.



*Cusk* launches JB-2 Loon  
Source: US Navy / Wikipedia



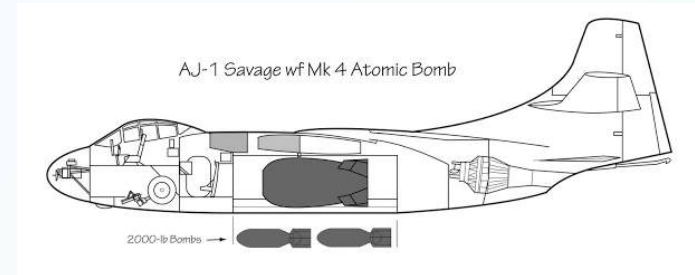
*Tunny* launches Regulus I.  
Source: US Navy / Wikipedia



# State-of-the-art in 1955

## Nuclear weapons

- Starting in the late-1940s, the Navy converted Essex and Midway-class aircraft carriers to handle and deploy nuclear weapons. The lead ship, *USS Oriskany* (CV-34), was commissioned in September 1950.
- The Federation of American Scientists reported that nuclear weapons were carried on Navy surface ships starting in 1954.
- The propeller-driven, carrier-based, heavy-attack AJ-1 Savage bomber was designed for weapons up to the 60 inch (1.52 m) diameter of a Mk-IV implosion bomb (similar to the Mk-III “Fat Man”), but was armed with the smaller Mk-V or Mk-VI. The AJ-1 began carrier operations in April 1950.
  - Mk-V yield: 6 - 120 kT; length: 10.7 feet (3.3 m); diameter: 44 inches (1.1 m); weight 3,025 - 3,175 pounds (1,372 - 1,440 kg).
  - Mk-V was the first bomb with automatic in-flight insertion (IFI) of the nuclear core.



AJ-1 Savage cross-section with Mk-IV bomb.  
Source: Tommy H. Thomason /  
[tailspintopics.blogspot.com](http://tailspintopics.blogspot.com)



Mk-V Source: Author's photo /  
National Nuclear Museum

# State-of-the-art in 1955

## Nuclear weapons

- The jet-powered, carrier-based A3D Skywarrior bomber entered service in 1956, replacing the AJ-1 Savage in the heavy nuclear attack role.
- The smaller Mk-7 and Mk-12 bombs, which could be carried on fighter aircraft, were introduced in 1952 and 1954, respectively.
  - Mk-7 implosion bomb yield: 8 - 61 kT; length: 15.2 feet (4.6 m); diameter: 2.5 feet (0.76 m); weight 1,680 pounds (762 kg).
  - Mk-12 gun-type bomb yield: 12 - 14 kT; length: 12.9 feet (3.9 m); diameter: 1.8 feet (0.56 m); weight 1,100 - 1,200 pounds (500 - 540 kg).



Mk-7. Source: Wikipedia



Mk-12 shape carried under the wing of a Navy FJ-4B Fury Source: US Navy photo / Wikipedia

# State-of-the-art in 1955

## Nuclear weapons

- The W5 nuclear warhead, derived from the Mk-V bomb, armed the Regulus I land-attack cruise missiles deployed on cruisers starting in 1955.
- W5 yield: 40 kT; length: 76 inches (1.9 m); diameter: 39 inches (1 m); weight 2,405 – 2,650 pounds (1,091 – 1,202 kg).
- Smaller nuclear warheads existed.
  - The 15 kT W9 warhead for the Army's 280 mm (11.1 inch) "atomic cannon" was tested in 1953; the similar W19 was introduced in 1955.
  - The 15 – 20 kT W23 warhead for 16 inch (406 mm) naval guns on battleships was introduced in 1956.
- Smaller and/or more powerful nuclear weapons were being developed and tested for future weapons systems:
  - 1959: 1<sup>st</sup> Regulus I submarine deterrent patrol likely was armed with the more powerful W27 2MT thermonuclear warhead, which became available in 1958.
  - 1960: 1<sup>st</sup> Polaris submarine deterrent patrol, 16 Polaris A1 missiles armed with W47 600 kT warheads
  - 1963: Mark 45 ASTOR torpedo operational with W34 11kT nuclear warhead.
  - 1965: UUM-44 SUBROC submarine-launched anti-submarine missile operational with W55 warhead with a yield reported variously as 1 – 5 kT or 250 kT.

# State-of-the-art in 1955

## Thermonuclear weapons

- Thermonuclear weapons were just being introduced to the US military inventory and they were very large.
- 28 Feb 1954: US detonated its first “deliverable” (non-cryogenic) thermonuclear device, code named Bravo.
- Mk-17 & Mk-24 bombs were the first operational thermonuclear weapons deployed by the US:
  - 24.7 ft. (7.52 m) long, 61.4 in (1.56 m) diameter, and weighed 21 tons (19,091 kg).
  - Yield: 10 – 15 MT
  - In production Oct 54 - Nov 1955
- Mk-15 bomb was the first relatively lightweight thermonuclear bomb created by the US:
  - 11.7 ft. long (3.56 m) long, 35 in (0.89 m) diameter, and weighed 7,600 lb. (3,450 kg)
  - Yield: 1.7 – 3.8 MT
  - First produced in 1955



Mk-17. Source: <http://www.castleairmuseum.org>



Mk-15. Source: Wikipedia



# State-of-the-art in 1955

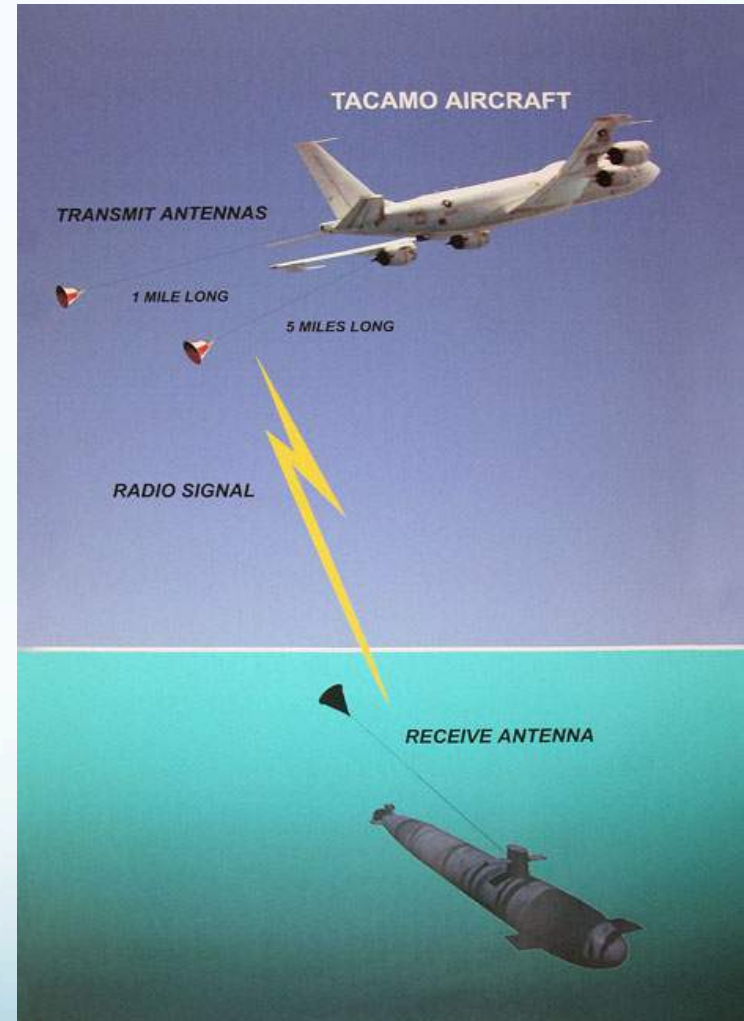
## Communications

- WW-II-era HF & VHF radio communications were available for vessels on the surface, as was short-range signaling via flags or flashing light.
- The only operational means for communicating with a submerged submarine was the AN/WQC-2, “Gertrude”, underwater telephone developed in 1945.
- Very Low Frequency (VLF) communications were not available in 1955.
  - VLF radio waves (3 – 30 kHz) can penetrate seawater to a depth of about 20 meters (66 feet).
  - Naval Research Laboratory (NRL) developed a VLF facsimile transmission system, known as “Bedrock”, that was the first system to provide reliable command and control communication from a single high-power transmitting station in the US to continuously submerged submarines operating in any region of the world.
  - Earliest demonstrations of this system were:
    - *USS Skate* (SSN-578) used the system successfully on its 1959 voyage to the North Pole.
    - *USS Triton* (SSN-586) used the system with good results throughout the first submerged circumnavigation of the globe, February-May 1960.
  - Subsequently, VLF communications systems were installed in all nuclear submarines, with communications via a VLF “crossed-loop” antenna and/or a floating wire antenna that trails behind the sub.

# State-of-the-art in 1955

## Communications

- No TACAMO aircraft available in 1955 to provide a backup VLF data and HF voice radio transmission capability to relay Emergency Action Messages from the President to submarines.
- 1962: 1<sup>st</sup> TACAMO tests
- 1969: System operationally deployed using EC-130Q *Hercules* cargo aircraft flying long-duration missions over the Atlantic and Pacific.
- Modern TACAMO aircraft are E-6B.



Source: [http://usnavymuseum.org/Ex2\\_TACAMO](http://usnavymuseum.org/Ex2_TACAMO)

# State-of-the-art in 1955

## Communications

- Extremely Low Frequency (ELF) communications not available in 1955.
  - Project Sanguine was proposed in 1968 to create a hardened ELF transmitter facility in Wisconsin & Michigan to transmit tactical orders one-way to US nuclear subs anywhere in the world, and survive a direct nuclear attack.
    - ELF radio waves can penetrate seawater to a depth of hundreds of feet.
    - Original design would have operated at 76 Hz and required about 800 MW of electric power.
  - Project ELF was the scaled-back 76 Hz system actually built in Wisconsin & Michigan.
    - Operational from 1989 to 2004, then retired due to high operating cost and regional ecological opposition.

# Submarine radio communications

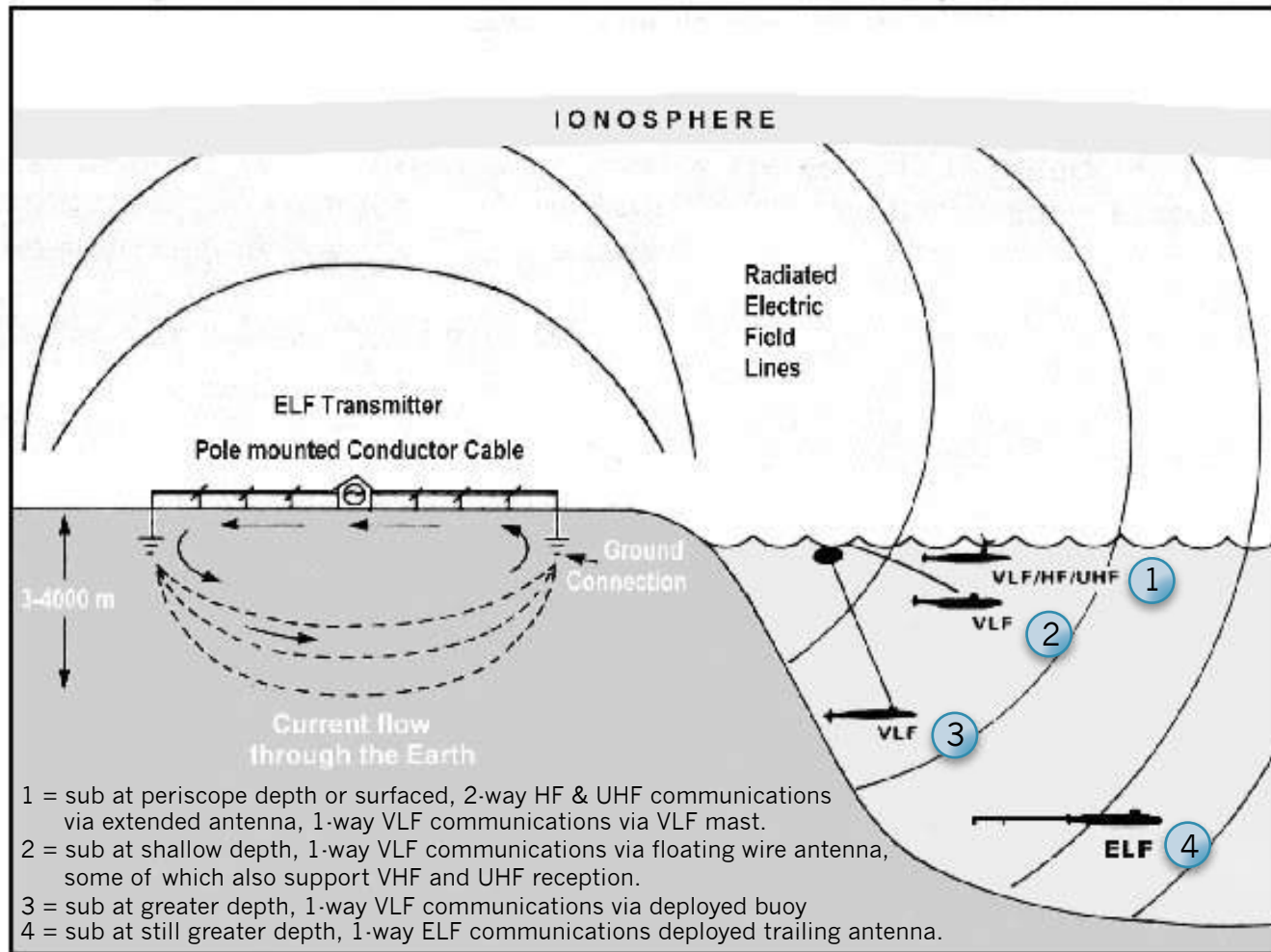


Image source: adapted from R. Romero and V. Lehtoranta, 22 November 1999.

# State-of-the-art in 1955

## Communications

- Satellite communications not available in 1955.
  - 4 Oct 1957: 1<sup>st</sup> satellite, Sputnik 1, launched into orbit
  - Aug 1960: Echo 1 launched; the world's 1<sup>st</sup> communications satellite capable of passively relaying radio signals to other points on Earth.
    - Relayed 1<sup>st</sup> recorded voice message (from President Eisenhower) on 13 Aug 1960 from CA to NJ
  - Jul 1962: Telstar 1 launched; the 1<sup>st</sup> communications satellite capable of relaying television signals from Europe to North America.
  - Early 1970s: Initial Navy operational use of satellite communications during Vietnam War
  - 1978-89: Fleet Satellite Communications (FLTSATCOM) system launched; operational 1981
  - 1984-90: Leasat launched & leased by Navy to add communications capacity:
  - 1993-2003: Ultra-High Frequency Follow-On (UFO) system launched to replace FLTSATCOM
  - 2012: Mobile User Objective System (MUOS) 1<sup>st</sup> launch. MUOS is designed to provide enhanced and secure communications, including smart-phone-like voice, video and data services for mobile Navy warfighters. MUOS was developed by Lockheed Martin Space Systems.
  - 2017: The MUOS satellite network achieved full operational capability and is expected to ensure the availability of UHF narrowband communications for the US Navy past 2025.

# State-of-the-art in 1955

## Navigation

- Well-established manual navigation available
  - Charts & sightings
  - Sextant, marine chronometer & Nautical Almanac
  - Dead-reckoning
- Long-range HF radio navigation available
  - The long-range radio navigation system LORAN, LOnge-range Aid to Navigation, later called LORAN-A, introduced in January 1943, was still the standard system in use in 1955.
  - LORAN-A range up to 1,500 miles, with accuracy of tens of miles.
  - LORAN-C became operational along the US east coast in 1957 and the system came under management of the US Coast Guard in August 1958. LORAN-C fixes typically were accurate to within hundreds of feet.
  - LORAN-C coverage areas included the US coasts, Mediterranean, Norwegian Sea, Central Pacific, and Bearing Sea.
  - 3 August 2010: all LORAN transmissions in North America from Canada and the US ceased broadcasting.
  - Loran-C was the underpinning of Enhanced Loran, or e-Loran, which some had envisioned as a backup system to satellite-based GPS.



# State-of-the-art in 1955

## Navigation

- No shipboard inertial navigation system existed in 1955.
  - Autonetics Division of North American Aviation conducted the first airplane flight of an inertial Autonavigator (XN-1) in 1950.
    - 1<sup>st</sup> flight of the all-solid-state Autonetics N6A inertial guidance system developed for the Navaho supersonic intercontinental cruise missile occurred in 1955.
  - In 1957 – 58, research ship *USS Compass Island* (AG-153) tested the Navy's first inertial navigation system, N6A-1 Autonavigator, which was a modification of the N6A.
    - The N6A-1 was installed on *Nautilus*, *Skate* and *Sargo* for their missions to the North Pole.
  - Ships Inertial Navigation System (SINS) originally was developed for the Fleet Ballistic Missile (FBM) submarine program
    - Developed by Sperry. One of the earliest transistorized systems introduced widely in Navy ships.
    - First deployed in 1960 on *USS Halibut* and for *USS Seadragon's* Arctic cruise.
    - Originally known as the N7, derived from the N6A-1. Re-designated Mk II SINS.
    - Manufactured from late 1950s to 2006.
  - Dual Miniature Ships Inertial Navigation System (DMINS)
    - Developed by Rockwell
    - First deployed in Los Angeles-class SSNs in 1976 and retrofit on selected other subs and aircraft carriers.

# State-of-the-art in 1955

## Navigation

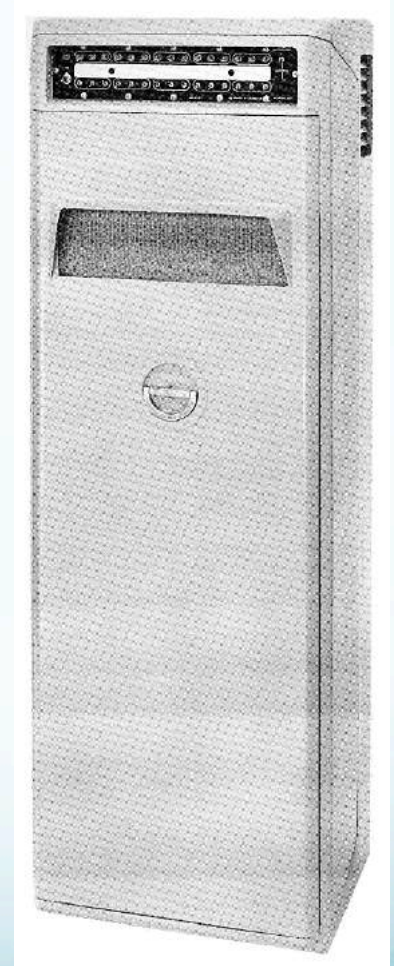
- No long-range VLF radio navigation was available in 1955
  - OMEGA was a global-range radio navigation system, operated by the US and six partner nations, with a set of very low frequency (VLF) fixed terrestrial radio beacons transmitting at 10 to 14 kHz.
  - Became operational in 1971; shut down in 1997 in favor of GPS.
- No satellite navigation system was available in 1955
  - TRANSIT
    - Development of the TRANSIT system began in 1958.
    - The first successful tests of the system were made in 1960, and the system entered Naval service in 1964.
    - TRANSIT provided continuous navigation satellite service initially for Polaris submarines and later for other military and civilian use.
    - Ceased navigation service in 1996; replaced by GPS.
  - Global Positioning System (GPS)
    - GPS project began in 1973.
    - 1st experimental Block-I GPS satellite was launched in 1978.
    - Achieved full operational capability in April 1995.



# State-of-the-art in 1955

## Shipboard Computers

- In 1955, no computer small enough to fit through a submarine's hatch existed.
- The 1<sup>st</sup> standard Navy shipboard computer, AN/UYK-1, was still years away.
  - This was the military designation of the Thompson Ramo Wooldridge TRW-130 computer introduced in 1961.
  - AN/UYK-1 was the processor in the AN/BRN-3 Submarine Navigation Subsystem developed by Westinghouse Electric Corporation (receiver) and TRW for Fleet Ballistic Missile (FBM) submarines.
    - AN/UYK-1 integrated TRANSIT satellite navigation and Ships Inertial Navigation System (SINS) data.
    - First installed in an FBM submarine on 31 December 1963, about two years after the start of Polaris submarine deterrent patrols in 1960.

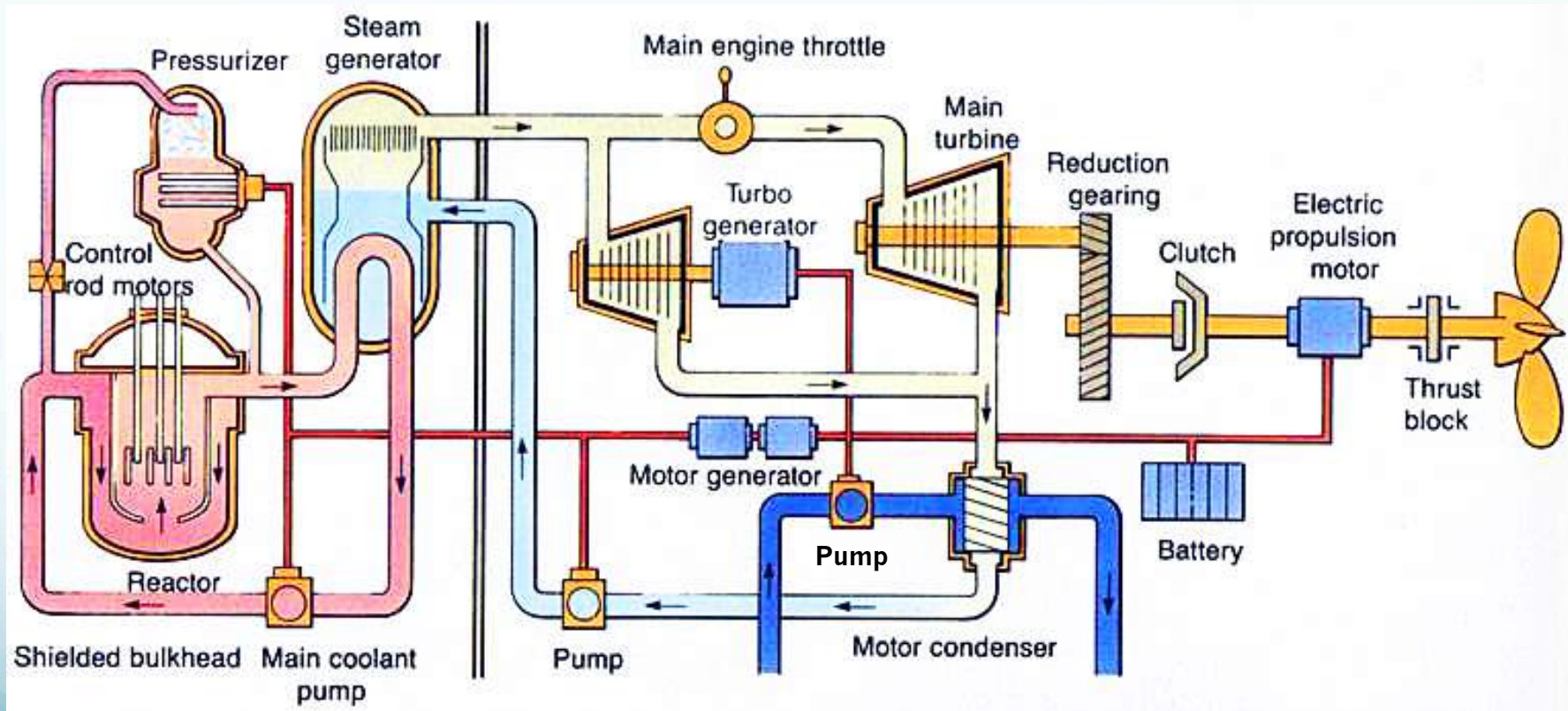


AN/UYK-1 computer  
Source: TRW M250-2U19 Rev B Feb 63

# Marine nuclear propulsion system basics

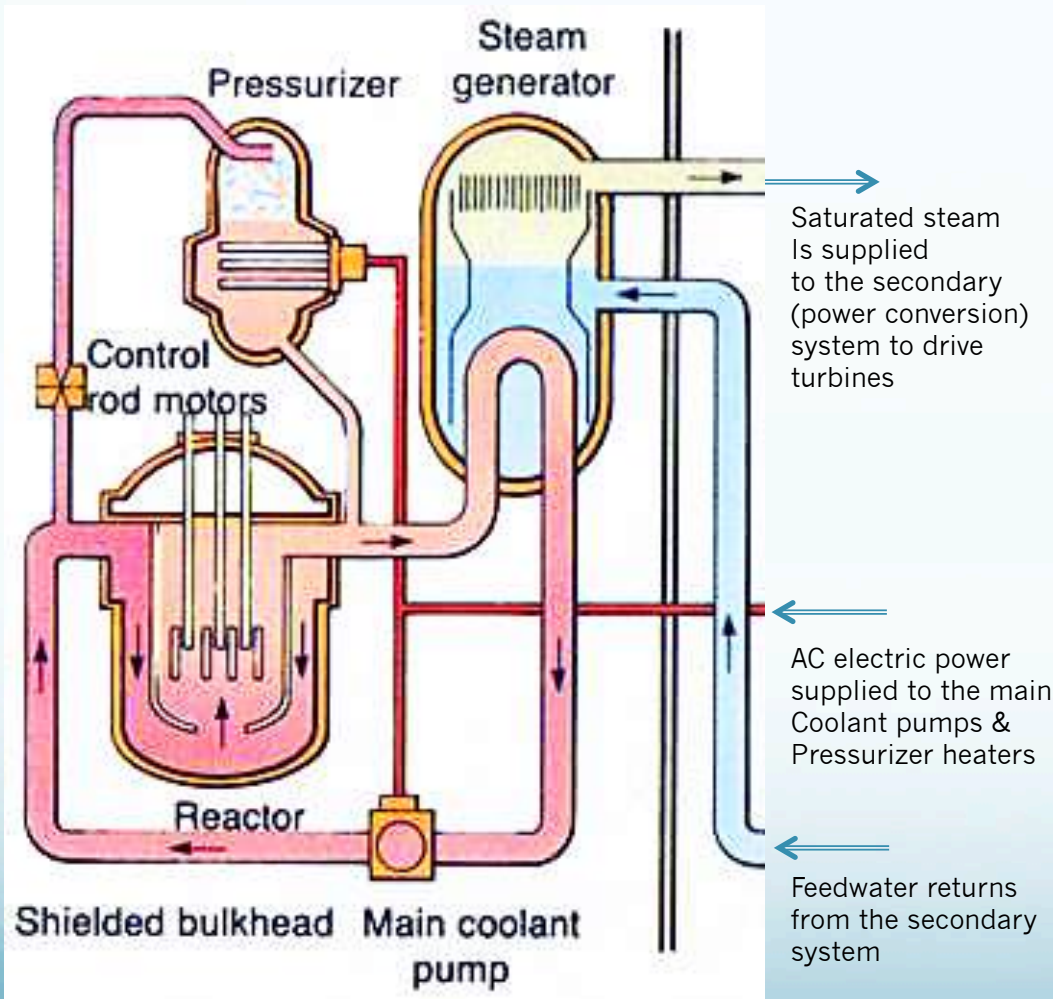
# PWR propulsion plant basic process flow diagram

The pressurized water reactor is the dominant type of marine reactor today



Source: subventures.net

# How heat transfer in a PWR primary system works



- The primary system is a closed-loop heat transport system that circulates ordinary water to move thermal energy from the reactor core (the heat source) to the steam generators (the heat sink) where the thermal energy is transferred into the secondary coolant to produce steam.
- Intact steam generator tubes prevent leakage of primary coolant into the secondary system.
- The primary coolant returns to the reactor to be reheated and circulated again through the primary system.
- The pressurizer is a "surge volume" with heaters and sprays that are used to maintain the correct high pressure in the PWR primary system and prevent the primary coolant water from boiling in the reactor core.



# How heat transfer in a PWR primary system works

- The reactor is the heat exchanger in the closed-loop primary system containing the heat source (the reactor fuel elements).
- The steam generator is the other heat exchanger in the closed-loop primary system containing the heat sink (the secondary coolant flowing through the steam generator tubes).
- The pressurizer maintains the PWR primary system at constant pressure.
- The continuous flow of the sub-cooled water primary coolant transfers heat from the reactor to the steam generators.
- In both heat exchangers, heat transfer in a sub-cooled liquid system at constant pressure is governed by the following:

$Q = UA \Delta T_m$ , where:

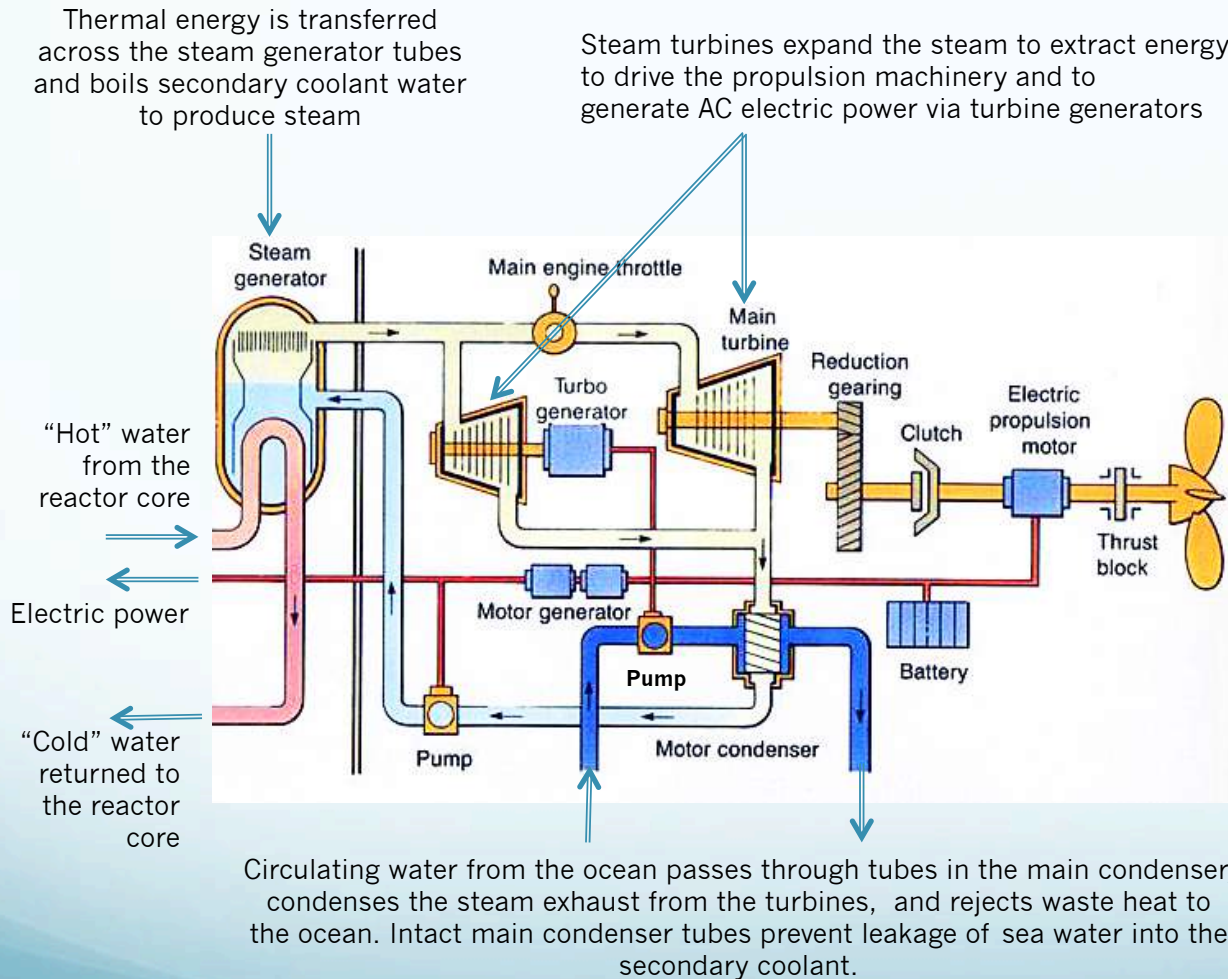
$Q$  = rate of heat transfer

$U$  = mean overall heat transfer coefficient

$A$  = heat transfer surface area of the heat exchanger

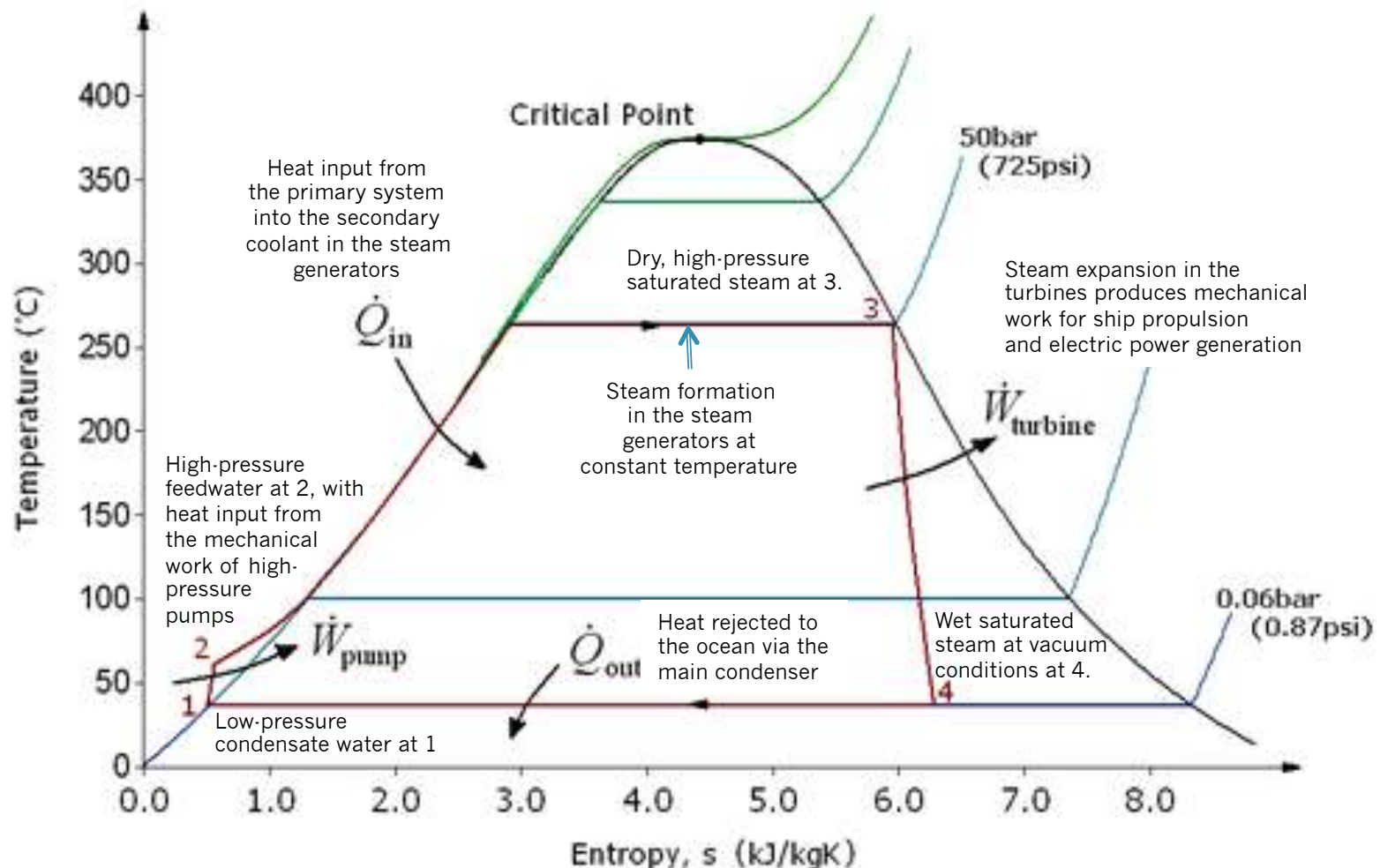
$\Delta T_m$  = logarithmic mean temperature difference across the heat exchanger

# How heat transfer in a Rankine-cycle secondary system works



- Turbine exhaust steam is condensed in the main condenser and this water is pumped back to the steam generator where it continues removing heat from the primary system to produce more steam.
- A motor-generator supplies DC loads (i.e., the ship's battery and an emergency DC propulsion motor) and can supply AC loads in an emergency.
- Some subs use electric motors for main propulsion. These subs have large turbine generators and no mechanical propulsion train.

# How heat transfer in a Rankine-cycle secondary system works



# Timeline



# Timeline highlights

**Mar 1939**

Enrico Fermi briefs Navy Department on atomic fission. Ross Gunn initiates Navy's 1<sup>st</sup> investigation into nuclear propulsion.

**2 Dec 42**

1<sup>st</sup> man-made self-sustaining nuclear chain reaction, CP-1 pile

**June 1946**

5 naval officers, including Rickover, plus 3 civilians detailed to Oak Ridge to learn nuclear technology

**Aug 48**

Rickover assigned Director, Naval Reactors Branch of BuShips

**Feb 49**

Rickover assigned to AEC's Div. of Reactor Development

**15 Nov 60**

1<sup>st</sup> U.S. Polaris SSBN deterrent patrol

**25 Nov 61**

1<sup>st</sup> nuclear aircraft carrier, *USS Enterprise* commissioned

**10 Jan 63**

*HMS Dreadnought* SSN 1<sup>st</sup> UK underway on nuclear power

**15 Jun 68**

1<sup>st</sup> UK SSBN deterrent patrol

**Jun 69**

1<sup>st</sup> Russian Yankee SSBN deterrent patrol

**1981**

1<sup>st</sup> Russian Typhoon-class SSBN commissioned

**11 Nov 81**

1<sup>st</sup> US Ohio-class SSBN commissioned

**23 Feb 83**

1<sup>st</sup> French SSN (Rubis) commissioned

**1987**

1<sup>st</sup> Chinese SSBN (Xia) operational

**1988**

Russian Charlie SSN leased by India

**23 Oct 04**

1<sup>st</sup> US Virginia-class SSN commissioned

**7 Feb 06**

1<sup>st</sup> US Ohio-class SSGN conversion, re-joins the fleet

**2007**

300<sup>th</sup> UK SSBN deterrent patrol

1940s

1950s

1960s

1970s

1980s

1990s

2000s

2010s

**17 Jan 55**

*USS Nautilus*  
world's 1<sup>st</sup> underway on nuclear power

**4 Jun 58**

November-class SSN 1<sup>st</sup> USSR underway on nuclear power

**3 Aug 58**

*USS Nautilus*,  
1<sup>st</sup> vessel to reach North Pole

**15 Apr 59**

*USS Skipjack*  
1<sup>st</sup> sub combining Albacore hull & nuclear power commissioned

**15 Sep 59**

USSR icebreaker *Lenin*, world's 1<sup>st</sup> nuclear surface ship voyage

**1971**

1<sup>st</sup> French sub (*Le Redoutable* SSBN) commissioned

**23 Aug 71**

1<sup>st</sup> Chinese sub (Han SSN) underway on nuclear power

**31 Dec 71**

1<sup>st</sup> USSR Alfa SSN commissioned

**3 May 1975**

1<sup>st</sup> Nimitz-class aircraft carrier commissioned

**17 Aug 77**

Russian icebreaker *Arktika*, 1<sup>st</sup> surface ship to reach North Pole

**Dec 94**

1<sup>st</sup> UK Vanguard-class SSBN deterrent patrol

**9 Mar 95**

Last of original 41 US Polaris SSBNs decommissioned

**19 Jul 97**

1<sup>st</sup> US Seawolf-class SSN commissioned

**1997**

1<sup>st</sup> French Triomphant-class SSBN deterrent patrol

**30 Jul 99**

*USS South Carolina*, last US nuclear cruiser, decommissioned.

**1 Mar 13**

Brazil inaugurates naval shipyard for building its 1<sup>st</sup> nuc sub

**2013**

Russia commissions 1<sup>st</sup> new-gen Borei SSBN & Yasen SSN

**2014**

1<sup>st</sup> Chinese 2nd-generation Jin SSBN operational

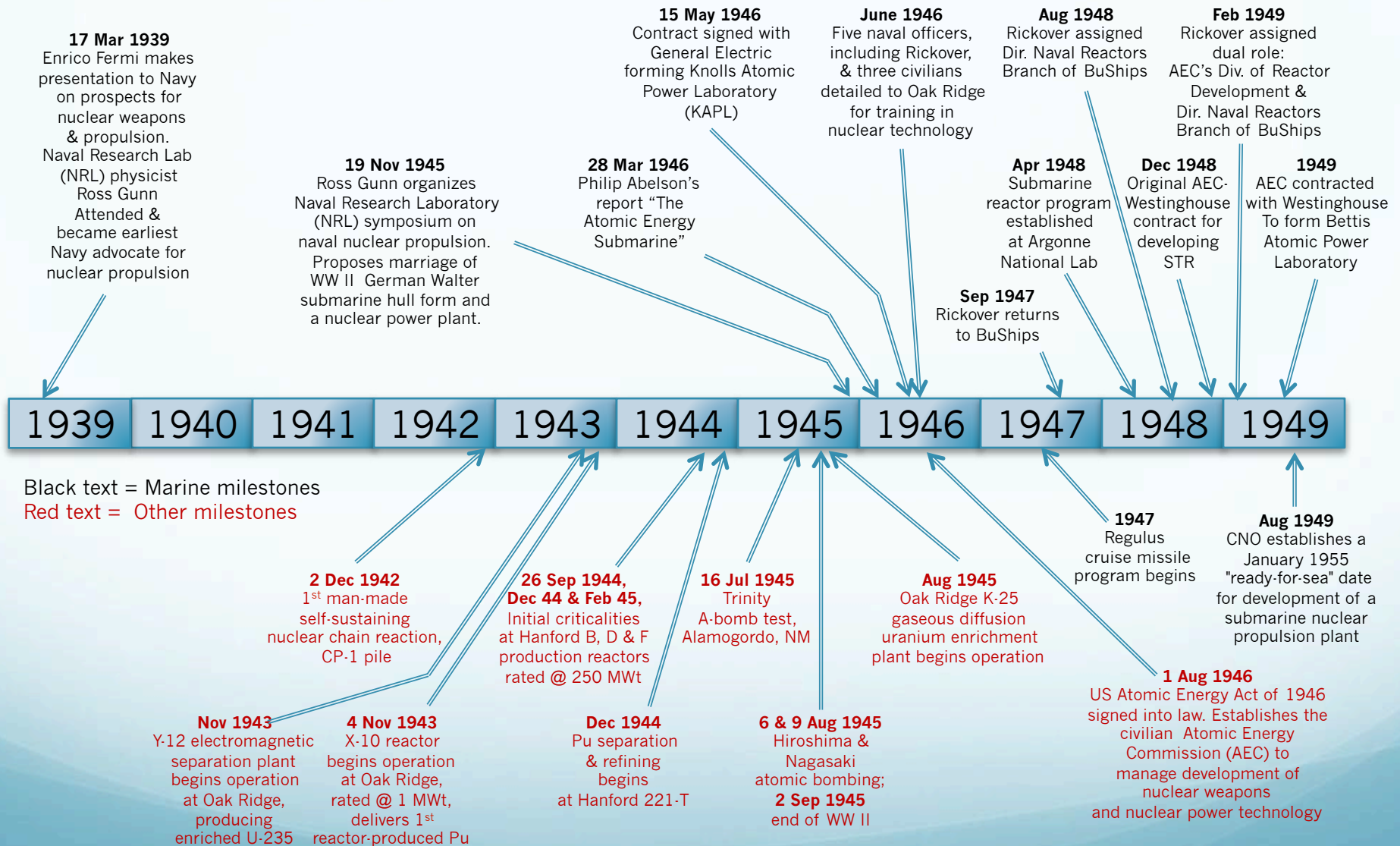
**19 Sep 14**

4000<sup>th</sup> US SSBN deterrent patrol

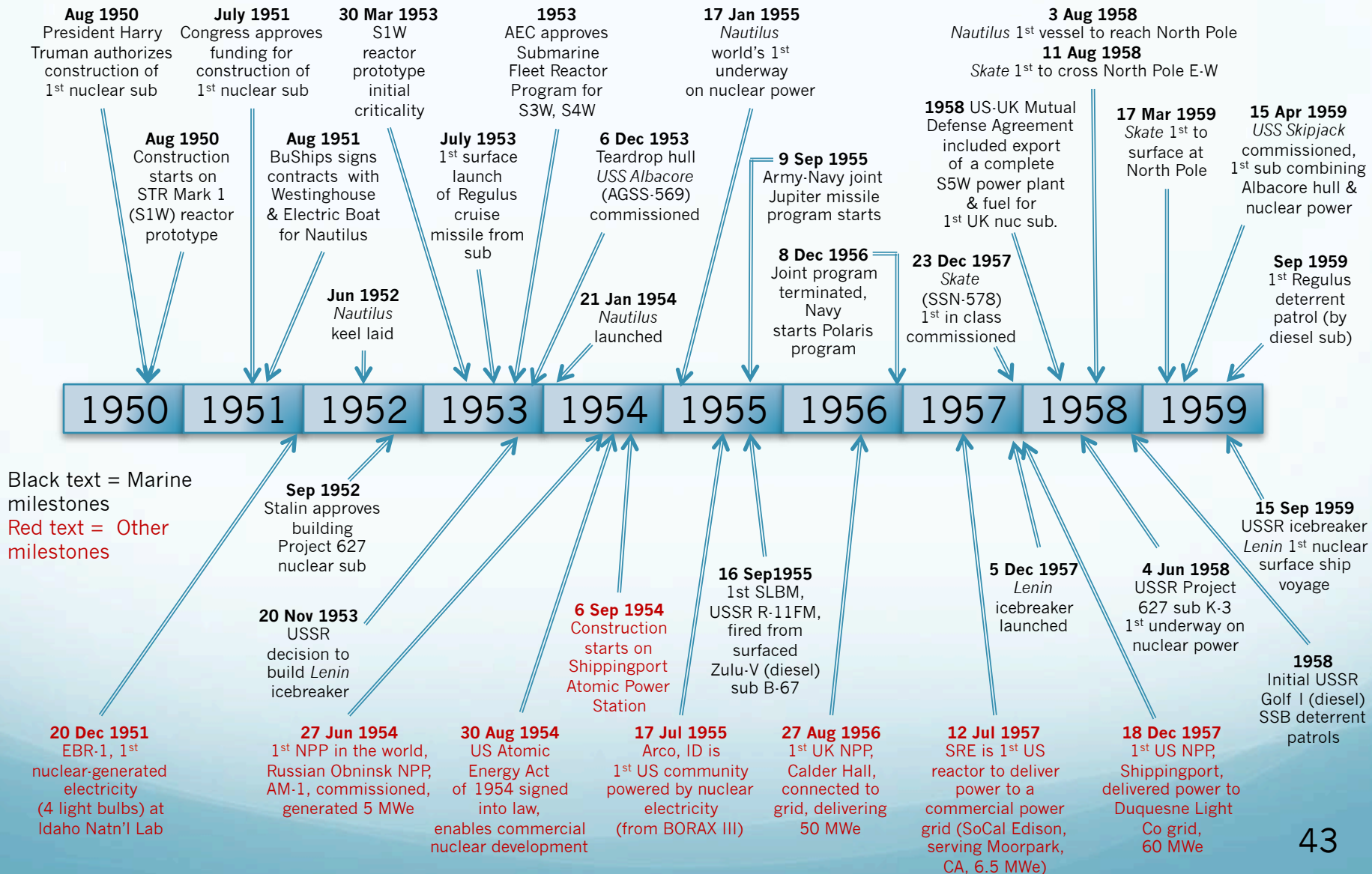
**16 Dec 14**

1<sup>st</sup> Indian indigenous nuclear sub, SSBN INS Arihant sea trials

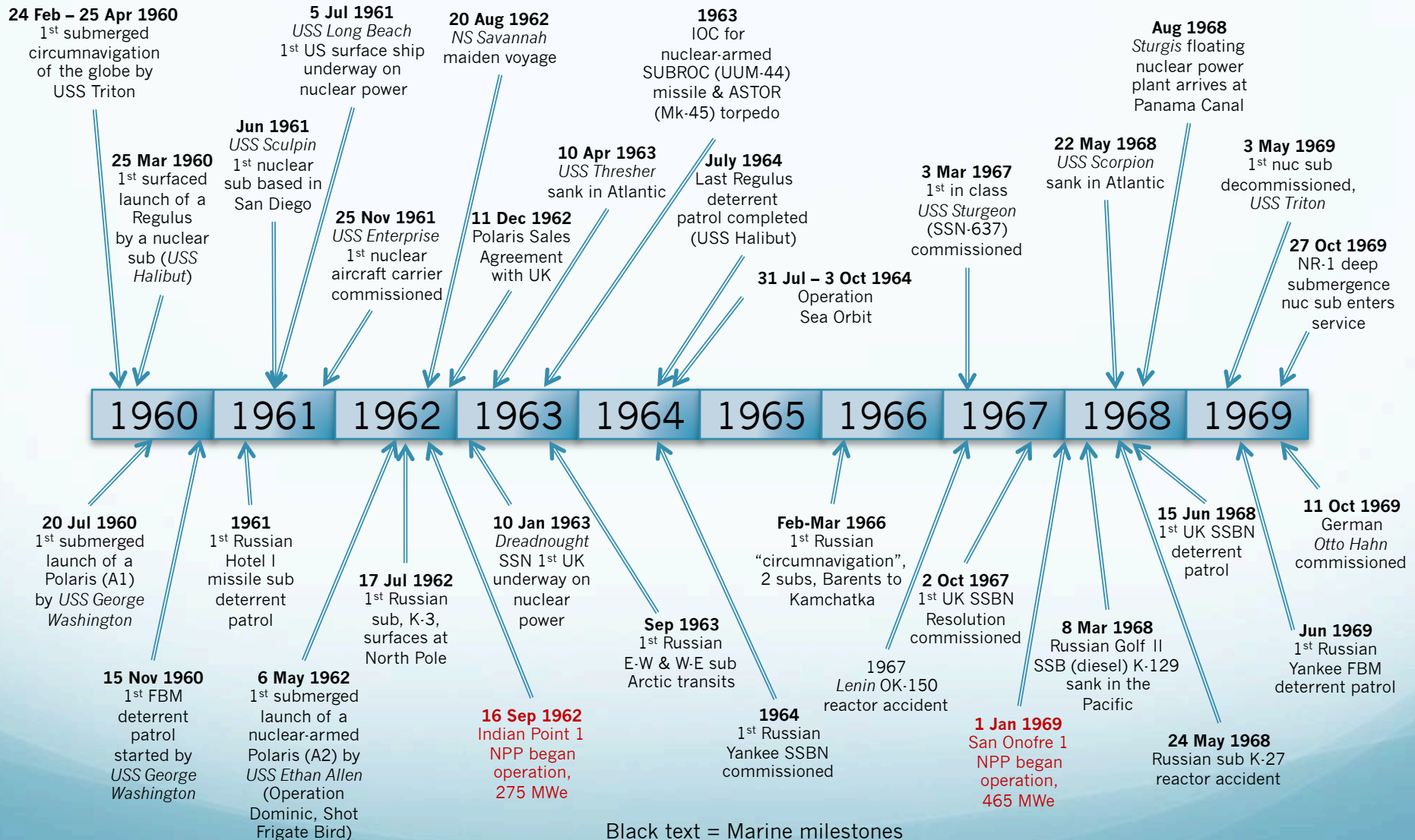
# Marine nuclear power timeline – 1940s



# Marine nuclear power timeline – 1950s

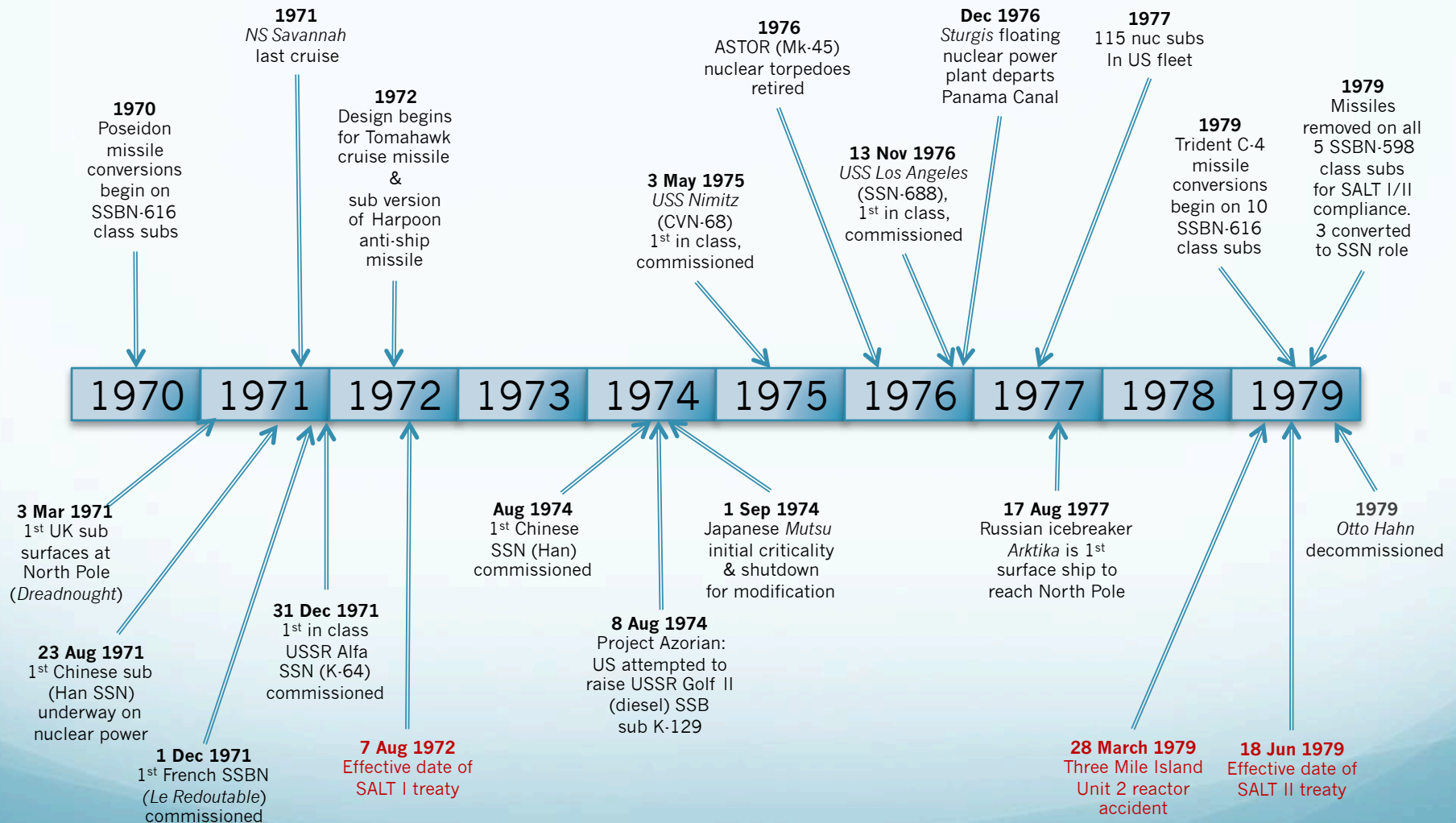


# Marine nuclear power timeline – 1960s



Black text = Marine milestones  
Red text = Other milestones

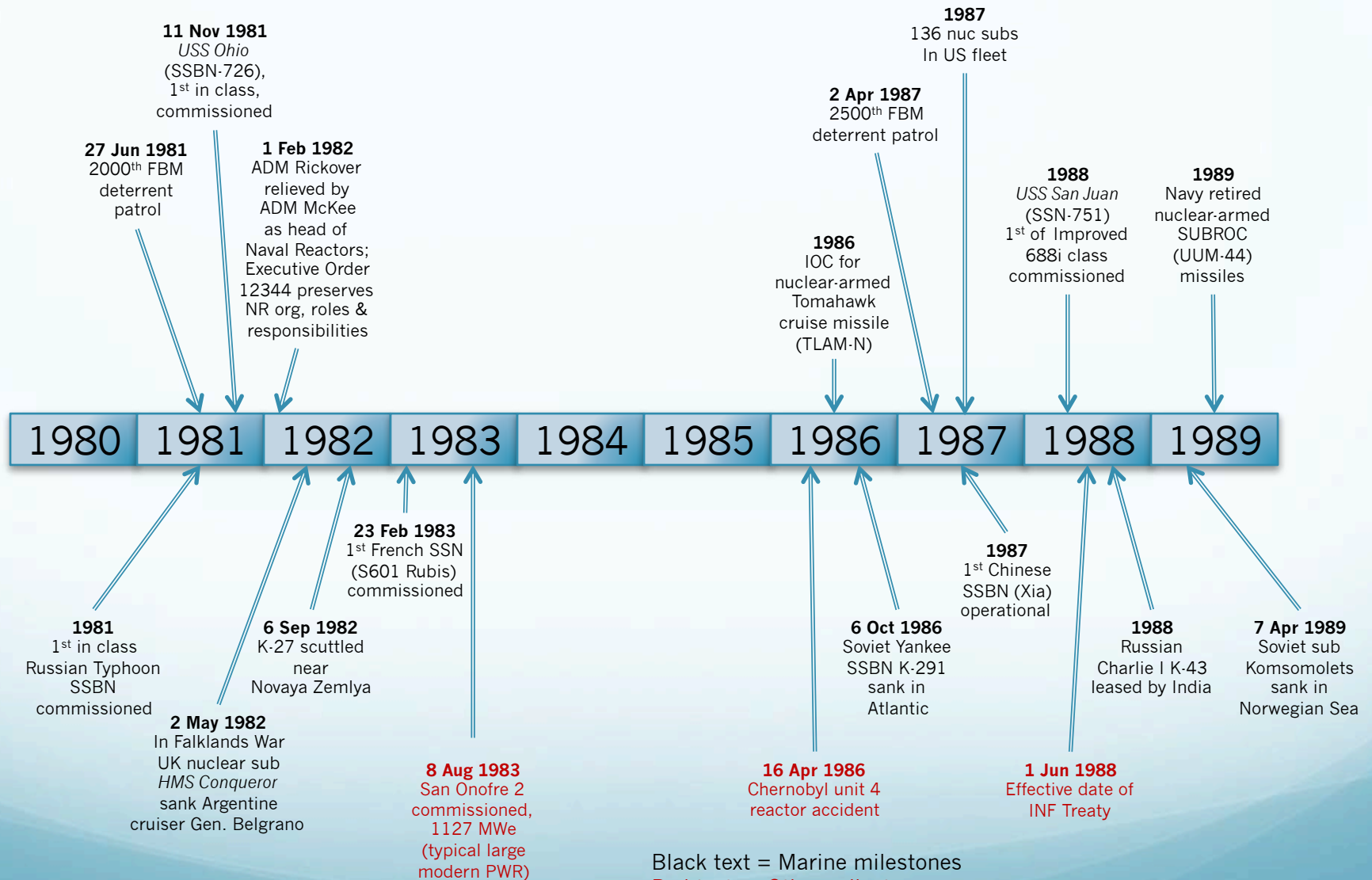
# Marine nuclear power timeline – 1970s



Black text = Marine milestones  
Red text = Other milestones



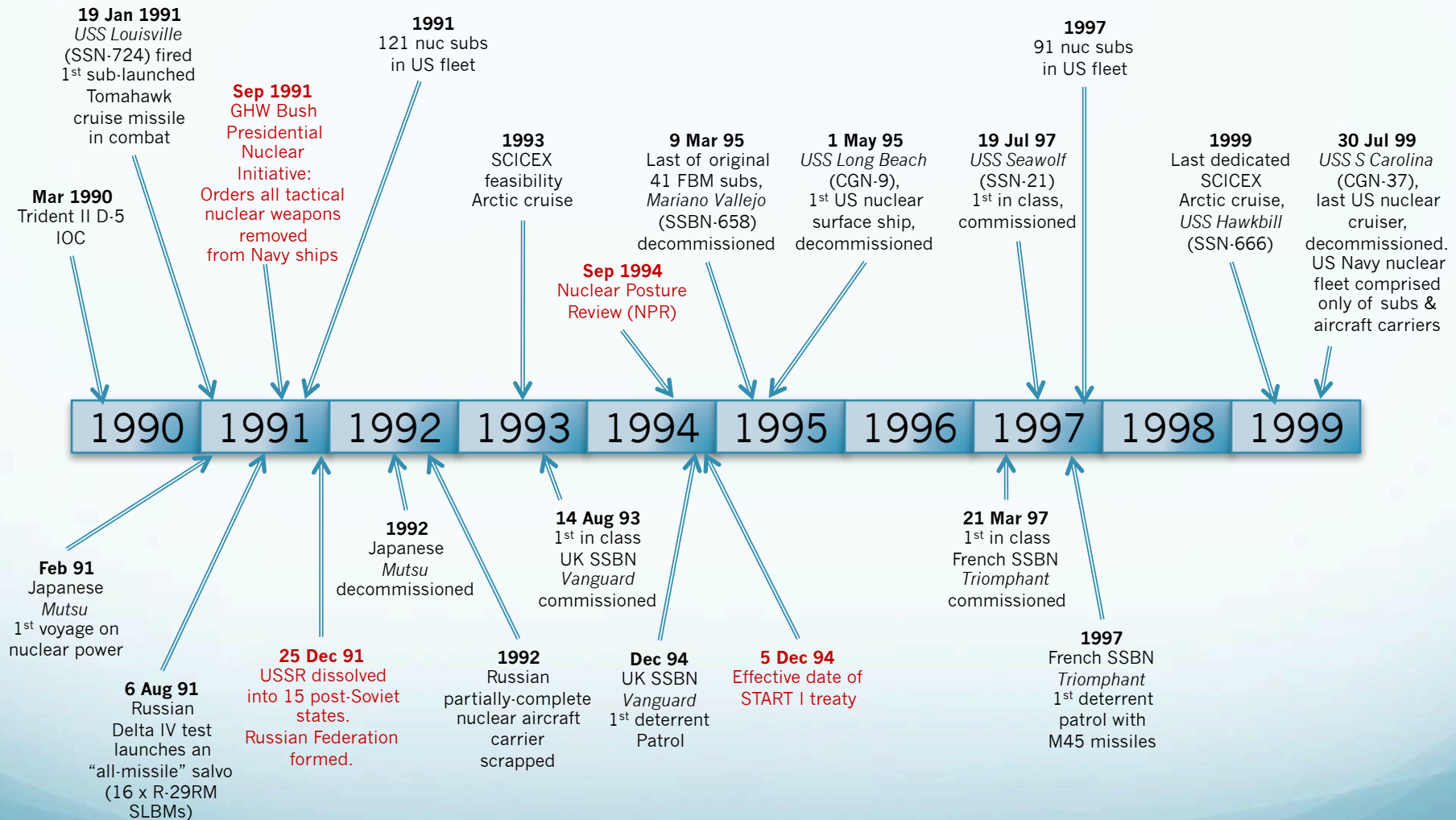
# Marine nuclear power timeline – 1980s



Black text = Marine milestones  
Red text = Other milestones

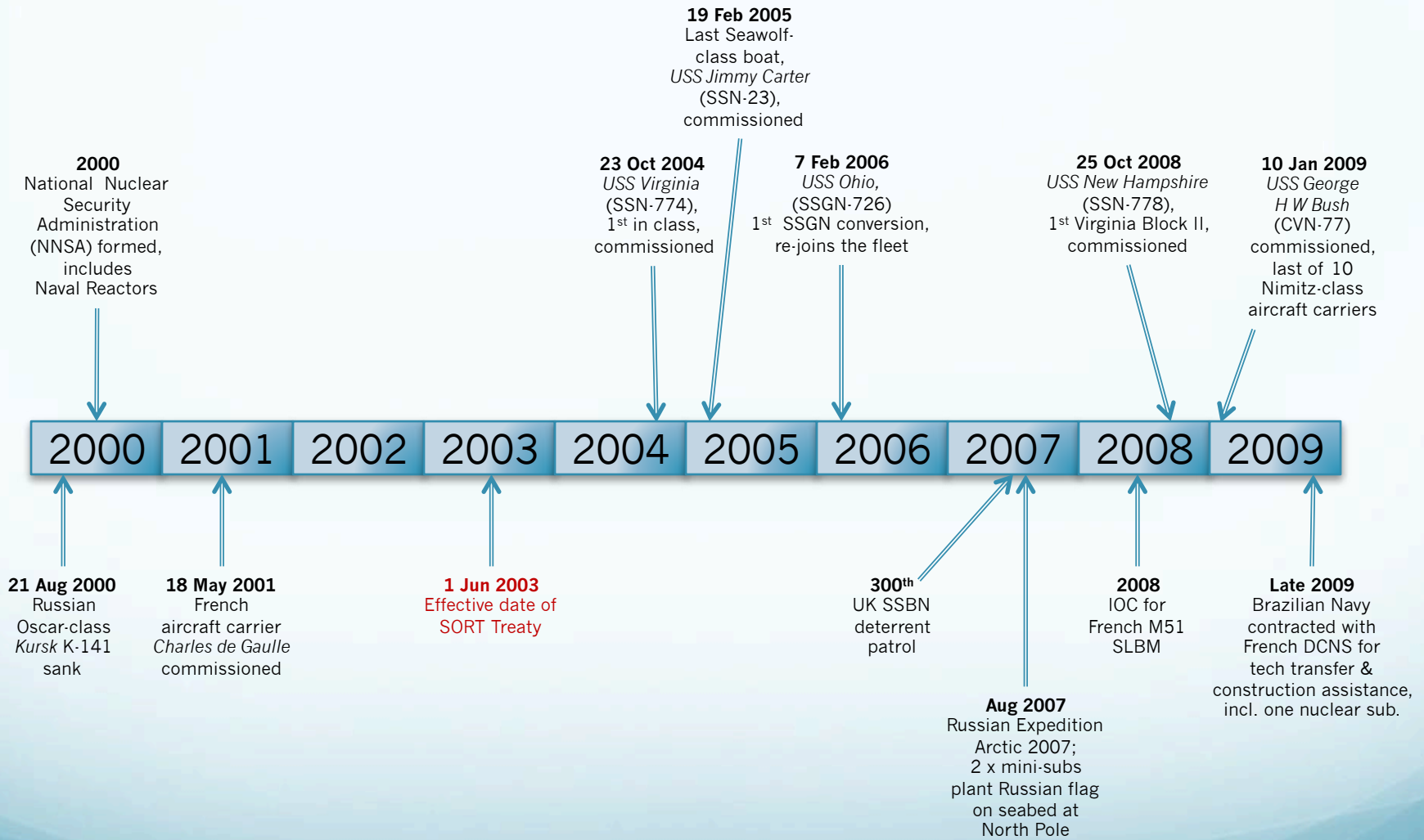


# Marine nuclear power timeline – 1990s



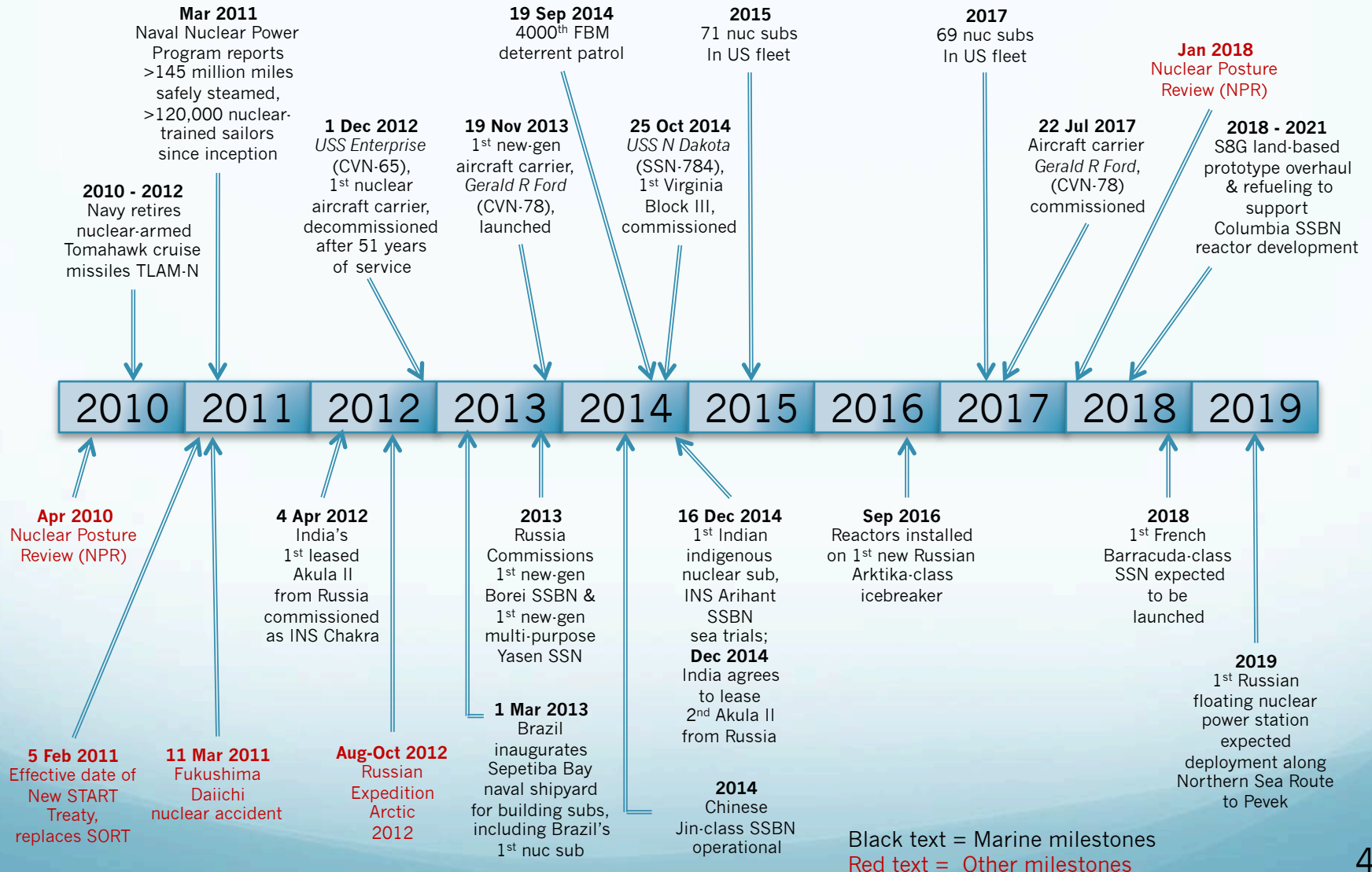
Black text = Marine milestones  
Red text = Other milestones

# Marine nuclear power timeline – 2000s

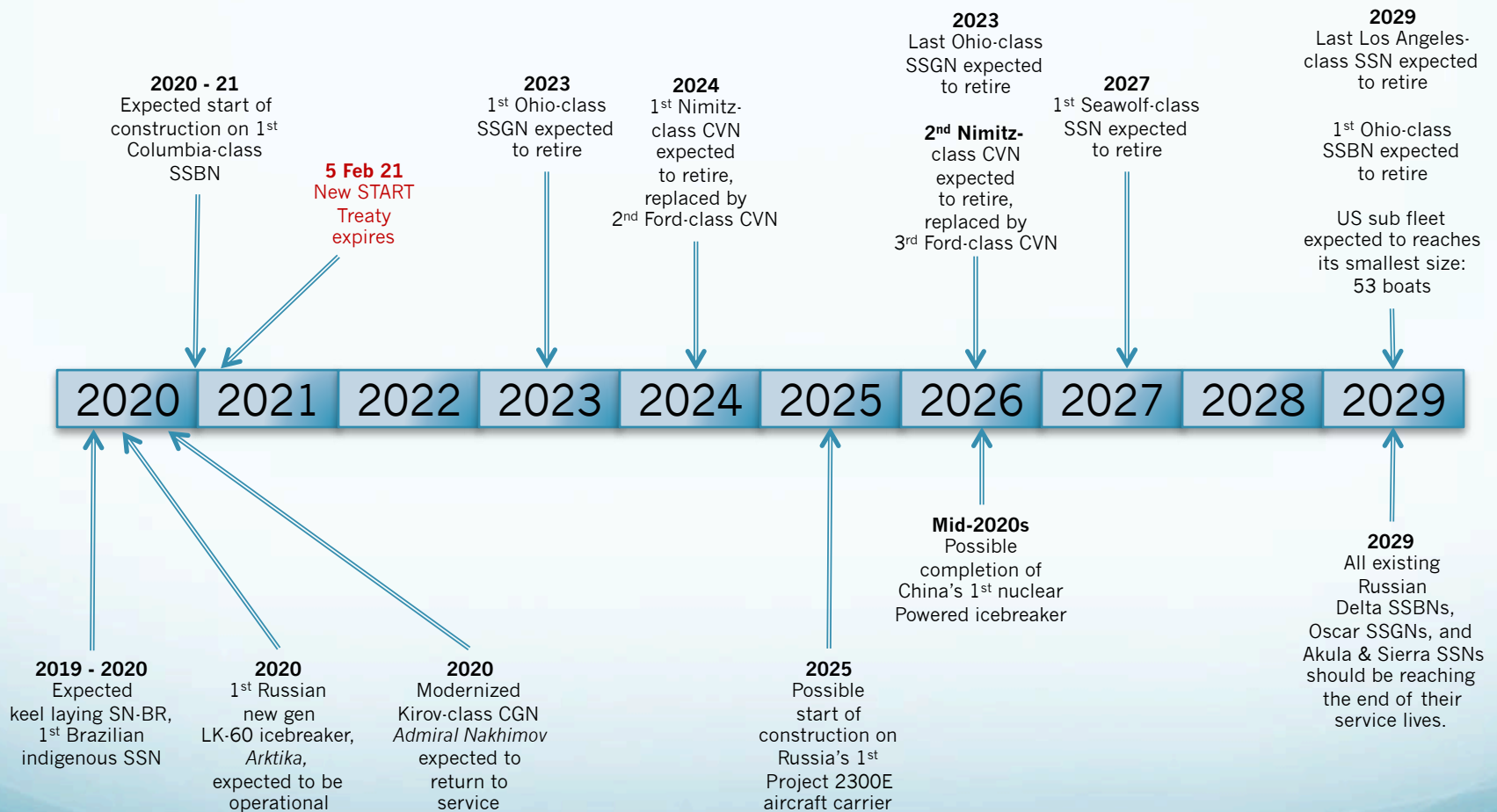


Black text = Marine milestones  
Red text = Other milestones

# Marine nuclear power timeline – 2010s



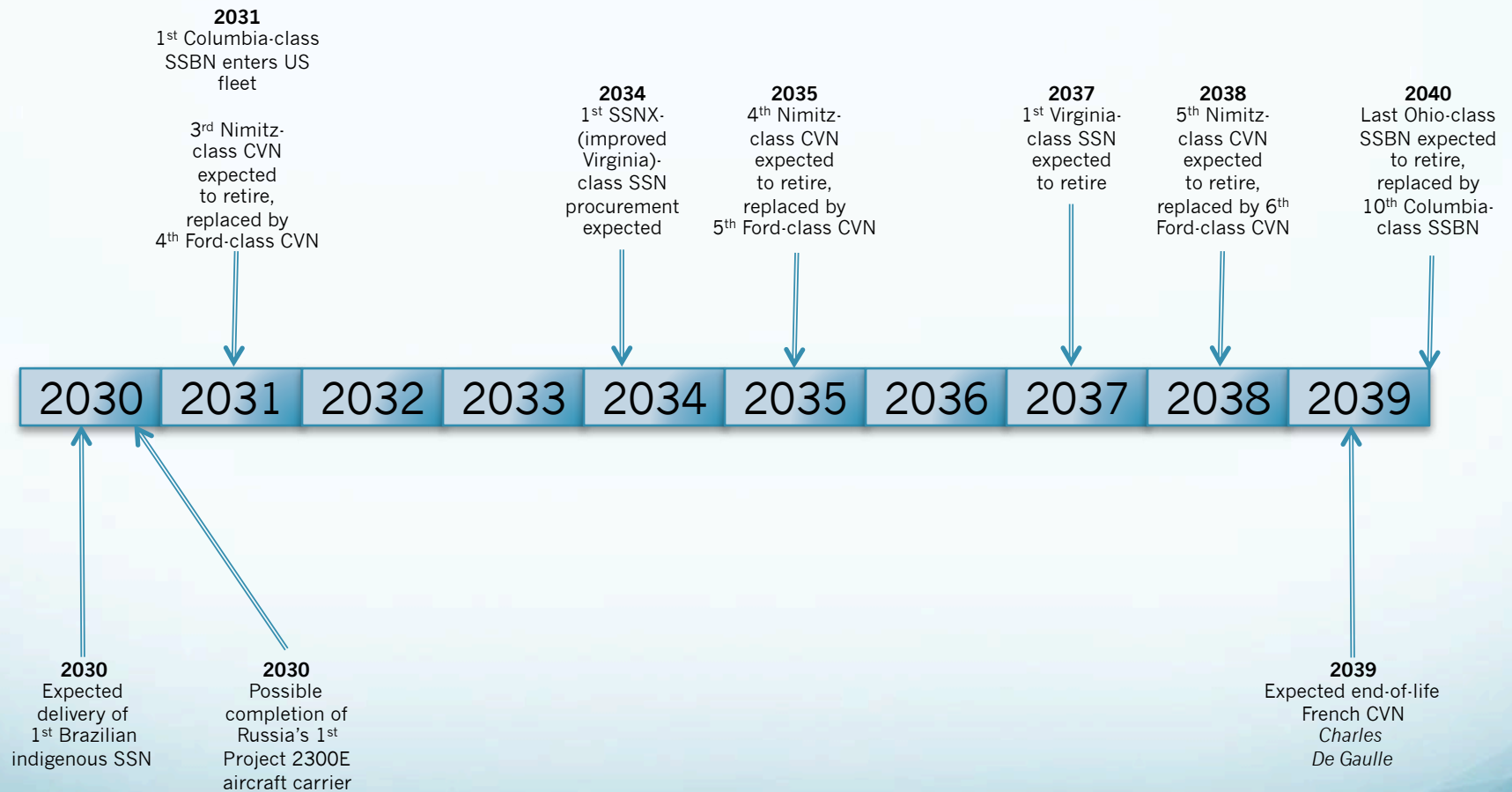
# Marine nuclear power timeline – 2020s



Black text = Marine milestones

Red text = Other milestones

# Marine nuclear power timeline – 2030s



Black text = Marine milestones

Red text = Other milestones

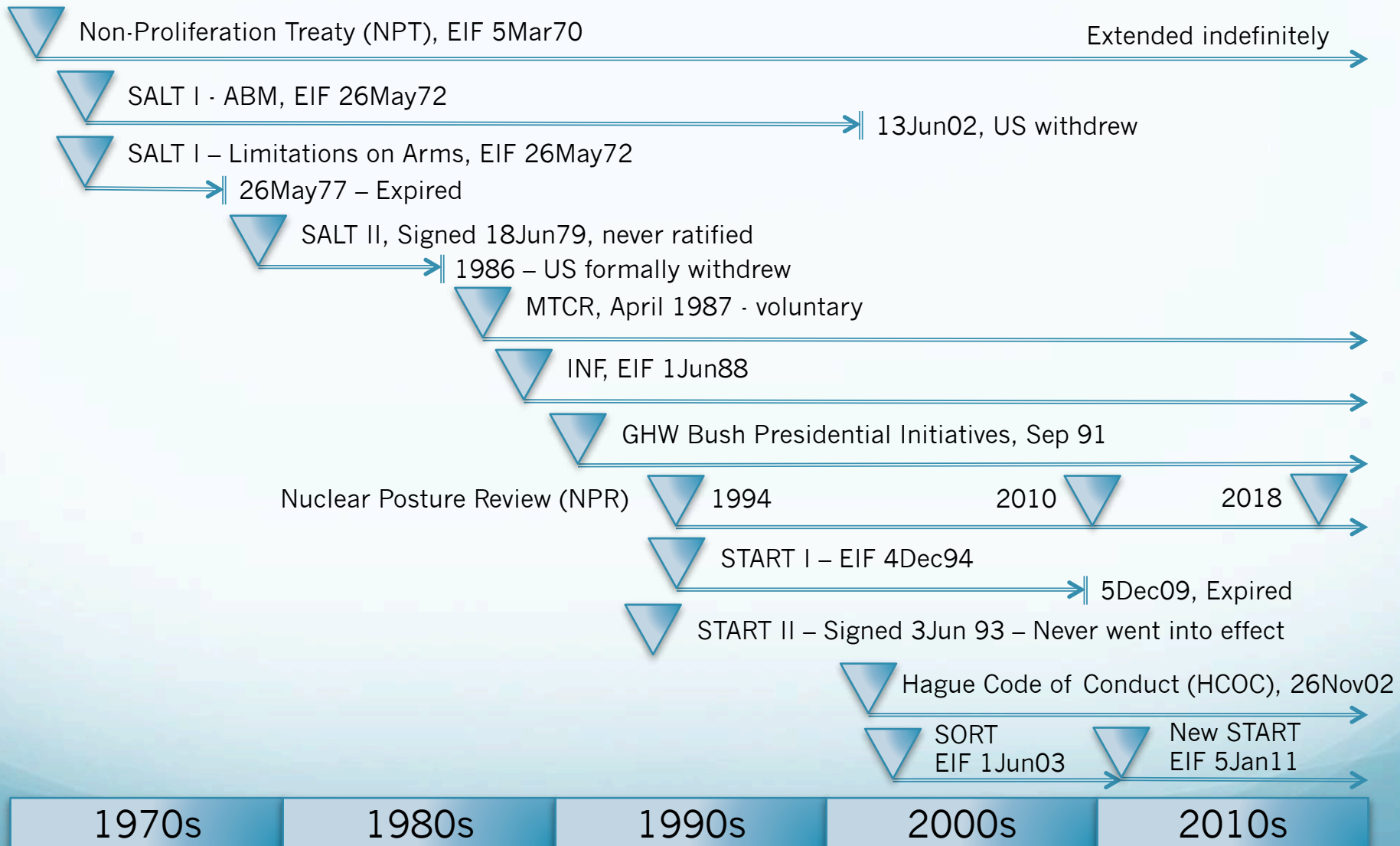
# Effects of nuclear weapons and missile treaties & conventions on the composition and armament of naval fleets



# Treaties & conventions

- 1963: Limited Test Ban Treaty
- 1970: Treaty on the Non-Proliferation of Nuclear Weapons (NPT, Non-Proliferation Treaty)
- 1972: Strategic Arms Limitation Treaty (SALT I)
- 1979: Strategic Arms Limitation Treaty II (SALT II)
- 1987: Missile Technology Control Regime (MTCR)
- 1988: Intermediate-range Nuclear Forces (INF) Treaty
- 1991: GHW Bush Presidential Nuclear Initiatives
- 1994: Clinton administration Nuclear Posture Review (NPR) 1994
- 1994: Strategic Arms Reduction Treaty (START I)
- 1993: Strategic Arms Reduction Treaty II (START II, never implemented)
- 2002: International Code of Conduct Against Ballistic Missile Proliferation (HCOOC, Hague Code of Conduct)
- 2003: Strategic Offensive Reductions Treaty (SORT, aka Treaty of Moscow)
- 2010: Obama administration Nuclear Posture Review (NPR) 2010
- 2011: New START (formally known as Measures for the Further Reduction and Limitation of Strategic Offensive Arms)
- 2018: Trump administration Nuclear Posture Review (NPR) 2018
- Future: Fissile Material Cutoff Treaty (FMCT)

# Timeline



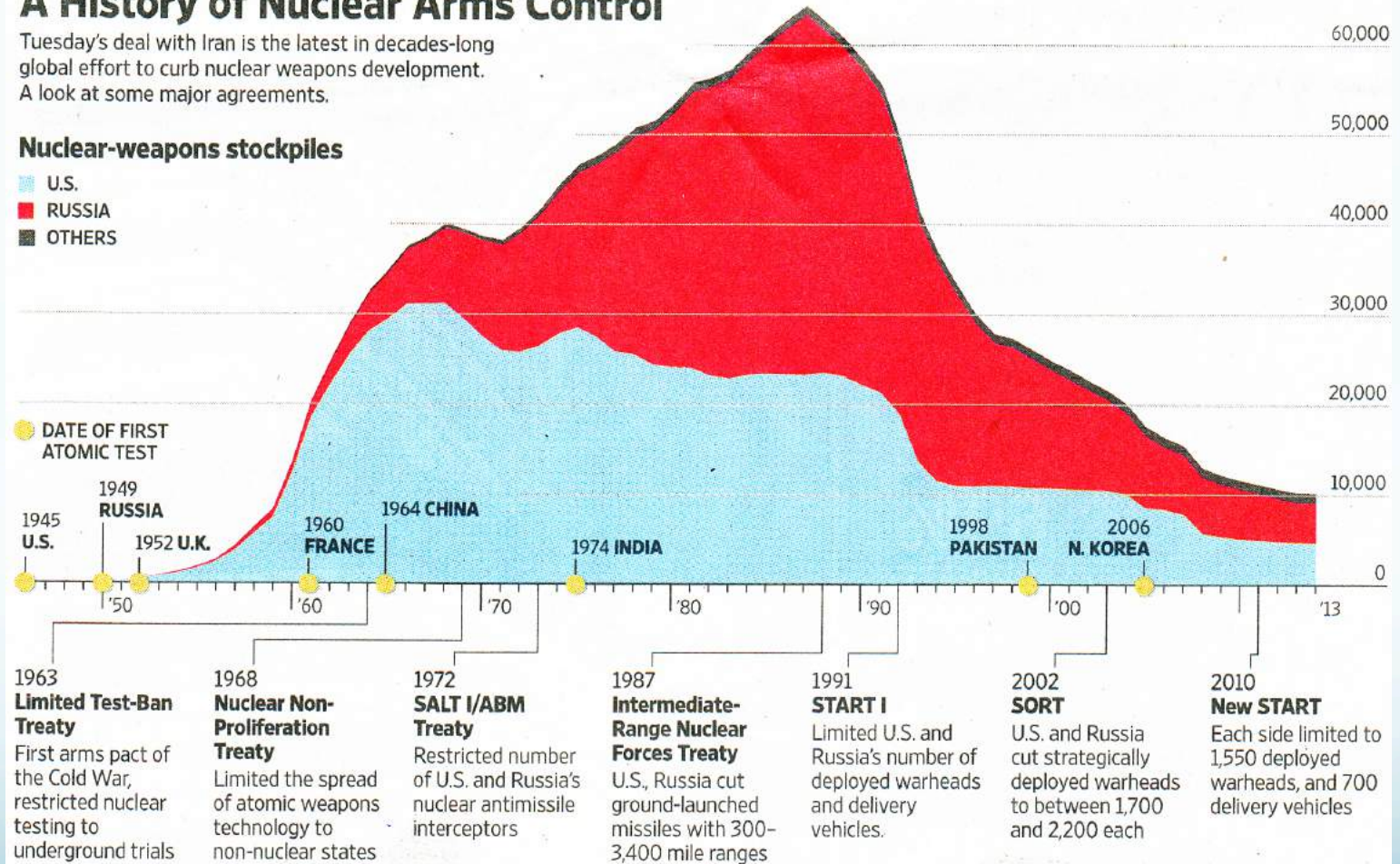
# Timeline

## A History of Nuclear Arms Control

Tuesday's deal with Iran is the latest in decades-long global effort to curb nuclear weapons development. A look at some major agreements.

### Nuclear-weapons stockpiles

■ U.S.  
■ RUSSIA  
■ OTHERS



Notes: Test date uncertain for Israel, which neither confirms nor denies having nuclear weapons; South Africa acknowledged having a limited nuclear arsenal, which it disassembled.


Sources: Arms Control Association; Stockholm International Peace Research Institute; Bulletin of the Atomic Scientists; Federation of American Scientists

THE WALL STREET JOURNAL

Source: Wall Street Journal

# Signatories of NPT & international missile control conventions

| Country     | NPT                       | MTCR                                    | HCOC              |
|-------------|---------------------------|---|-------------------|
| USA         | Signed, weapons state     | Member                                  | Subscribing state |
| Russia      | Signed, weapons state     | Member                                  | Subscribing state |
| UK          | Signed, weapons state     | Member                                  | Subscribing state |
| France      | Signed, weapons state     | Member                                  | Subscribing state |
| China       | Signed, weapons state     | Non-member, agreed partial compliance   | Not subscribing   |
| Germany     | Signed, non-weapons state | Member                                  | Subscribing state |
| Japan       | Signed, non-weapons state | Member                                  | Subscribing state |
| India       | Not signed, weapons state | Member                                  | Subscribing state |
| Brazil      | Signed, non-weapons state | Member                                  | Not subscribing   |
| Italy       | Signed, non-weapons state | Member                                  | Subscribing state |
| Canada      | Signed, non-weapons state | Member                                  | Subscribing state |
| Australia   | Signed, non-weapons state | Member                                  | Subscribing state |
| North Korea | Withdrew, weapons state   | Non-member                              | Not subscribing   |
| Israel      | Not signed, weapons state | Non-member, agreed voluntary compliance | Not subscribing   |
| Pakistan    | Not signed, weapons state | Non-member                              | Not subscribing   |
| Iran        | Signed, non-weapons state | Non-member                              | Not subscribing   |

 Marine nuclear propulsion state

 Interest in marine nuclear propulsion

# Treaty on the Non-Proliferation of Nuclear Weapons

aka Non-Proliferation Treaty (NPT)

- NPT is an international treaty intended to:
  - Limit the spread of nuclear weapons and weapons technology
  - Support the goal of achieving nuclear disarmament
  - Recognize the right to peacefully use nuclear technology
- The NPT entered into force on 5 Mar 1970; effective period 25 years.
  - The NPT is reviewed at 5-year intervals in meetings called “Review Conferences of the Parties to the Treaty of Non-Proliferation of Nuclear Weapons.”
  - On 11 May 1995, a consensus of the Review Conference agreed to extend the NPT indefinitely.
- A total of 191 states joined the NPT with North Korea withdrawing in 2003.
  - Non-signators are India, Israel, North Korea, Pakistan and South Sudan
- The NPT consists of a preamble and eleven articles.
  - Article IV affirms, “...the inalienable right of all the Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes...”
- Application of the NPT is guided by IAEA document INFCIRC/153 (Corrected), June 1972, *The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons*



# Treaty on the Non-Proliferation of Nuclear Weapons

aka Non-Proliferation Treaty (NPT) (cont'd)

- The NPT does not explicitly regulate the production, use, and disposition of highly-enriched uranium (HEU) for naval nuclear reactors.
  - Paragraph 14 of *INFCIRC/153 (Corrected)*, June 1972 allows a state to withdraw nuclear material from safeguards if it is being used for a “nonproscribed military activity” (i.e., for use in naval reactor fuel), and , “...the nuclear material will not be used for the production of nuclear weapons or other nuclear explosive devices.”
  - This is viewed by some as a legal loophole in the NPT, which allows fissile material to be removed from IAEA monitoring for use in non-weapons military applications.
  - On 21 Mar 2014, the *New York Times* reported that US naval reactors use about 4,500 pounds (2,041 kg) of HEU per year. Other worldwide naval reactor programs combined use about 1,500 pounds (680 kg) of HEU per year.
    - The *New York Times* article claims that the US has 150 tons (136,078 kg) of weapons-grade uranium set aside for use in naval fuel.



# Treaty on the Non-Proliferation of Nuclear Weapons

## aka Non-Proliferation Treaty (NPT) (cont'd)

- NPT and the NATO Multilateral Force (MLF)
  - MLF was a US proposal, supported by the Eisenhower, Kennedy and Johnson administrations, to create a NATO fleet of nuclear-armed ballistic missile submarines (SSBNs) and surface warships armed with Polaris missiles.
    - The Italian cruiser *Giuseppe Garibaldi* was the only vessel refitted with four launchers for Polaris missiles
  - The vessels in the fleet would have been manned by NATO crews and under NATO command, thereby increasing European control over their own nuclear defense in the event of a war with the Soviet Union
    - MLF also was seen as a way to preclude independent nuclear weapons development by some European nations.
  - MLF failed in the 1965 – 66 timeframe because the US and the European NATO members could not agree on many key factors that would govern international nuclear collaboration under MLF, including: vessel type (submarine and/or surface ship launch platforms), basing, and financing.
  - The extent of dysfunction within NATO was punctuated on 21 June 1966 by France's withdrawal from NATO.
  - It has been reported that the Soviet Union made elimination of the NATO MLF a pre-condition to their signing the NPT on 1 July 1968. By that date, the MLF no longer was an issue.

# INFCIRC/153 (Corrected), June 1972

“The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons.”

- This is the International Atomic Energy Agency’s (IAEA) implementing document for the Non-Proliferation Treaty (NPT).
- The “basic undertaking” of INFCIRC/153 is to define the commitments that must be made by states accepting the NPT.

“The Agreement should contain, in accordance with Article III.1 of the Treaty on the Non-Proliferation of Nuclear Weapons, an undertaking by the State to accept safeguards, in accordance with the terms of the Agreement, on all source or special fissionable material in all peaceful nuclear activities within its territory, under its jurisdiction or carried out under its control anywhere, for the exclusive purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices.”

# Use of HEU in naval reactors is permitted by Paragraph 14 of INFCIRC/153 (Corrected), June 1972

## NON-APPLICATION OF SAFEGUARDS TO NUCLEAR MATERIAL TO BE USED IN NON-PEACEFUL ACTIVITIES

14. The Agreement should provide that if the State intends to exercise its discretion to use nuclear material which is required to be safeguarded thereunder in a nuclear activity which does not require the application of safeguards under the Agreement, the following procedures will apply:
- (a) The State shall inform the Agency of the activity, making it clear:
    - (i) That the use of the *nuclear material* in a non-proscribed military activity will not be in conflict with an undertaking the State may have given and in respect of which Agency safeguards apply, that the *nuclear material* will be used only in a peaceful nuclear activity; and
    - (ii) That during the period of non-application of safeguards the *nuclear material* will not be used for the production of nuclear weapons or other nuclear explosive devices;
  - (b) The Agency and the State shall make an arrangement so that, only while the *nuclear material* is in such an activity, the safeguards provided for in the Agreement will not be applied. The arrangement shall identify, to the extent possible, the period or circumstances during which safeguards will not be applied. In any event, the safeguards provided for in the Agreement shall again apply as soon as the *nuclear material* is reintroduced into a peaceful nuclear activity. The Agency shall be kept informed of the total quantity and composition of such unsafeguarded *nuclear material* in the State and of any exports of such material; and
  - (c) Each arrangement shall be made in agreement with the Agency. The Agency's agreement shall be given as promptly as possible; it shall only relate to the temporal and procedural provisions, reporting arrangements, etc., but shall not involve any approval or classified knowledge of the military activity or relate to the use of the *nuclear material* therein.

# Strategic Arms Limitation Treaty

## (SALT I)

- President Richard Nixon & Soviet General Secretary Leonid Brezhnev signed SALT I 26 May 72. The treaty was ratified by Congress 3 Aug 72.
- SALT I was comprised of two major parts:
  - Anti-ballistic Missile (ABM) Treaty
    - Allowed one ABM site with 100 ABM launchers
    - US withdrew from the ABM treaty 13 Jun 2002
  - Interim Agreement on the Limitation of Strategic Offensive Arms
    - Set quantitative limits on ICBM and submarine-launched ballistic missile (SLBM) launchers (higher than either side possessed at the time), but no limit on the number of warheads.
      - Freeze the number of strategic ballistic missiles at 1972 levels
    - Limits included:
      - US could have a maximum of 44 SSBN subs with 710 SLBM launchers; Russia could have a maximum of 62 SSBN subs with 950 SLBM launchers.
      - NATO and the US could operate a maximum of 50 SSBNs with a maximum of 800 SLBM launchers among them
        - U.S had 41 Polaris SSBNs and the UK had 4 SSBNs.
        - France was not a NATO member between 1966 and 2009
    - This part of SALT had a 5 year duration and expired in 1977. It was intended to be superseded by SALT II, which was not ratified.

# Strategic Arms Limitation Treaty II

## (SALT II)

- President Jimmy Carter & Soviet General Secretary Leonid Brezhnev signed SALT II on 18 Jun 1979 but the treaty was not ratified by Congress.
- Limits: Each side was limited to 2,400 (dropping to 2,250 in Jan 1981) deployed launchers for strategic nuclear delivery vehicles, including ICBMs, SLBMs, heavy bombers, and air-launched missiles with ranges > 600 km (373 mi).
  - Various ceilings on missiles carrying multiple, independently-targeted reentry vehicles (MIRVs)
  - Ban until Dec 1981 on deployment of sea-launched cruise missiles with range > 600 km (373 mi)
- While not being ratified, some of the SALT II limits were voluntarily observed by the US and the Soviet Union.
- US formally withdrew in 1986.

# Missile Technology Control Regime (MTCR)

- MTCR is an informal and voluntary partnership among member states that originally was created to prevent the proliferation of delivery systems for nuclear weapons; specifically delivery systems capable of carrying a 500 kg (1,102 lb.) payload for at least 300 km (186 mi).
  - Applies to ballistic missiles, cruise missile, and other unmanned aerial vehicles (UAVs)
- Established in April 1987 by Canada, France, Germany, Italy, Japan, Great Britain, and the US. MTCR functions primarily as an export control group.
  - In 1992, MTCR expanded to apply to all weapons of mass destruction, not just nuclear weapons
  - In early 2018 there were 35 member states. India became the newest member on 27 June 2016.
  - Not all members have agreed to the same level of compliance
- The MTCR “no undercut” policy means that if one member denies the sale of some missile technology to another country, then all members must adhere.
- In 2002, the MTCR was supplemented by the *International Code of Conduct Against Ballistic Missile Proliferation* (Hague Code of Conduct).
- MTCR has been successful in stopping some international missile programs and limiting the export of others.
- However, MCTR has its limitations; India, Iran, Israel, North Korea, and Pakistan continue to advance their indigenous missile programs. For example:
  - Israel’s Popeye Turbo and India’s Nirbhay long-range submarine-launched subsonic cruise missiles
  - The Russia – India BrahMos joint-venture that developed the BrahMos family of medium-range anti-ship supersonic cruise missiles and is developing the a hypersonic cruise missile.



# Intermediate-range Nuclear Forces (INF) Treaty

- President Ronald Reagan & General Secretary Mikhail Gorbachev signed the INF treaty on 8 Dec 1987. It was ratified by Congress in May 1988. Entry into force date: 1 Jun 1988
  - Eliminated nuclear and conventional intermediate range (500 – 5,500 km; 311 – 3,418 mi) ground-launched ballistic and cruise missiles.
    - Focus was on eliminating all US Pershing II ballistic missiles and ground-launched cruise missiles (Gryphon GLCMs) and all Soviet SS-4, SS-5 and SS-20 ballistic missiles.
  - INF did not directly affect submarine-launched land-attack nuclear weapons. However, it did raise their importance.
    - Nuclear-armed submarine-launched Tomahawk cruise missile (TLAM-N, BGM-109A) entered service in 1986, with a range of 2,494 km (1,550 mi).
    - As a result of the US Nuclear Posture Review 2010, TLAM-N was withdrawn from service and their nuclear warheads were dismantled by 2012.
  - Since 2005, Russia repeatedly has reported that it was considering withdrawing from the INF treaty.

# Intermediate-range Nuclear Forces (INF) Treaty (cont'd)

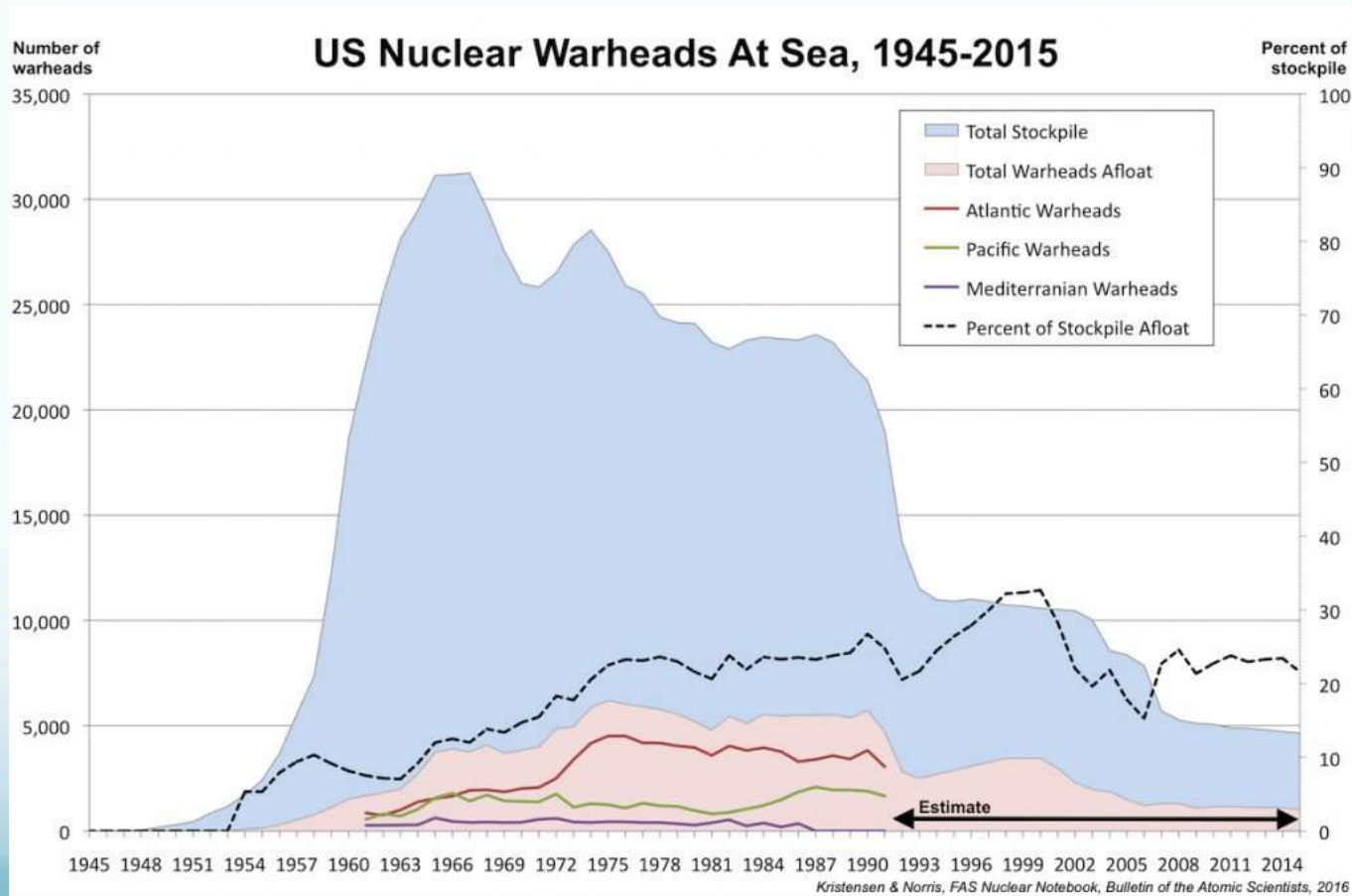
- Current Issues:
  - July 2014: The US formally notified Russia that it considered them in breach of the treaty for developing and possessing prohibited weapons:
    - A new long-range, ground-launched cruise missile (GLCM)
    - A new short-range “ICBM” with a range < 5,500 km, likely the RS-26.
  - 15 – 16 November 2016: The US and Russia met in Geneva on “to discuss questions relating to compliance with the obligations assumed under” the 1987 agreement.
  - 6 December 2017: Congressional Research Service issued a report, *“Russian Compliance with the Intermediate Range Nuclear Forces (INF) Treaty.”* Main points were:
    - The 2015, 2016, and 2017 State Department reports, *“Adherence to and Compliance with Arms Control, Nonproliferation, and Disarmament Agreements and Commitments,”* repeated the claim made first in their 2014 report that Russia had violated the INF Treaty.
    - The INF-violating new, long-range, GLCM was identified as the 9M729 (NATO code named SSC-8), which is manufactured by the Novator Design Bureau. This GLCM may be related to Russia’s 3M-54 Kalibr long-range, sea-launched cruise missile, also manufactured by Novator.

# Presidential Nuclear Initiative

- Issued by President George H. W. Bush in September 1991.
- Not a treaty. This was a unilateral action by the US
- The President ordered the Navy to “withdraw all tactical nuclear weapons from its surface ships and submarines,” including:
  - Carrier Air Wing aircraft-delivered nuclear weapons (B57 & B61 gravity bombs).
  - Tomahawk Land Attack Missile - Nuclear (TLAM-N, with 200 kT W80 warhead), which was carried on some Los Angeles-class SSNs and some surface ships.
  - The withdrawal was completed in early 1992.
- Several Navy tactical nuclear weapons already had been retired:
  - ASTOR (Mark 45) torpedo with an 11 kT W34 warhead was retired in 1976.
  - SUBROC (UUM-44) submarine-launched anti-submarine missile with a 1 – 5 kT W55 nuclear depth charge were retired in 1989.
  - ASROC (RUR-5) surface ship-launched anti-sub missile with a 10 kT W44 nuclear depth charge were retired in 1989. The conventional warhead versions remain in operational use.
  - RIM-2D Terrier BT-3A(N) anti-aircraft missile with a 1 kT W45 nuclear warhead were retired in 1990.
  - RIM-8B & -8D Talos anti-aircraft missile with a 2 - 5 kT W30 nuclear warhead were retired in 1979.
- Did not affect the strategic submarine-launched ballistic missiles (SLBMs) carried by the SSBN fleet.

# US Nuclear Warheads at Sea

After implementation of the Bush Presidential Nuclear Initiative and the subsequent final retirement of the TLAM-N, the Federation of American Scientists reported in 2013: “In 1987, the US Navy possessed more than 3,700 non-strategic nuclear weapons for use by almost 240 nuclear-capable ships and attack submarines in nuclear battles on the high seas. Today the number is zero.”



Source: <https://fas.org/blogs/security/2016/02/nuclear-weapons-at-sea/68>

# Nuclear Posture Review

## NPR 1994

- Issued by the Clinton administration.
- Not a treaty. This was a unilateral review by the US
- As a follow-on to the 1991 George H.W. Bush Presidential Nuclear Initiative to remove tactical nuclear weapons from Navy ships, NPR 1994 allowed the Navy to maintain Tomahawk Land Attack Missile - Nuclear (TLAM-N) qualifications for some Los Angeles-class submarines.
- The Federation of American Scientists (FAS) reported in 2013:
  - Periodic unarmed TLAM-N test launches from attack submarines were conducted through 2005.
  - The operational missiles were stored on land, and never made it back to sea.
  - Secretary of the Navy Instruction SECNAVINST 8120.1, dated 18 February 2010, *"Department of Navy Nuclear Weapons Responsibilities and Authorities,"* included provisions related to maintaining the Tomahawk Land Attack Missile - Nuclear (TLAM-N).
- NPR 1994 also determined that the strategic needs of the US could be met with 14 of the 18 Ohio-class SSBNs. The four oldest Ohio-class boats would be removed from SSBN service and converted into guided missile submarines (SSGNs) capable of conducting conventional land attack with cruise missiles and special operations.

# Strategic Arms Reduction Treaty

## (START I)

- Signed by President George H. W. Bush & Soviet President Mikhail Gorbachev on 31 July 1991
- Break-up of the Soviet Union in December 1991 contributed to a three year delay between signing the treaty and its entry into force.
  - The Lisbon Protocol, which adapted the original signed treaty to the political situation in the new Russian Federation, was signed on 23 May 1992
    - Four post-Soviet states, Russia, Belarus, Kazakhstan & Ukraine, were recognized as parties to START I in place of the Soviet Union, but only Russia was designated a nuclear weapon state.
    - Belarus, Kazakhstan, and Ukraine assumed an obligation to join the NPT as non-nuclear states and eliminate all START I accountable weapons and associated facilities within 7 years.
- EIF 5 Dec 1994; effective for 15 years; expired 5 Dec 2009; superseded by New START.
- Basic limits:
  - Each side limited to 1,600 operational delivery vehicles, including ICBMs, SLBMs and nuclear-capable bombers
  - Maximum of 6,000 deployed strategic nuclear warheads + other warhead limits
  - Maximum “throw weight” of 3,600 metric tons.
- Treaty bans testing of missiles with more warheads than established in the treaty, and bans any new ballistic missiles with more than 10 warheads.



# Strategic Arms Reduction Treaty II

## (START II)

- Signed by President George H. W. Bush and Russian Federation President Boris Yeltsin on 3 Jan 1993.
- This treaty never went into effect (entered into force):
  - Ratified by the US Senate on 26 January 1996.
  - After a long delay, during which the treaty became less relevant, Russia ratified the treaty on 14 April 2000.
  - On 14 June 2002, Russia withdrew from START II in response to US withdrawal from the SALT I Anti-Ballistic Missile (ABM) Treaty on 13 June 2002.
  - START II was replaced by SORT on 1 June 2003.
- Intended limits:
  - By December 31, 2004, the aggregate number of warheads on deployed ICBMs, SLBMs, and heavy bombers shall not exceed a number between 3,800 to 4,250. The following limits also apply.
    - 2160 warheads attributed to deployed SLBMs;
    - 1200 warheads attributed to deployed ICBMs of types to which more than one warhead is attributed; and
    - 650 warheads attributed to deployed heavy ICBMs.

# Strategic Arms Reduction Treaty II

## (START II) (cont'd)

- Intended limits (cont'd):
  - By December 31, 2007, the aggregate number of warheads on deployed ICBMs, SLBMs, and heavy bombers shall not exceed a number between 3,000 to 3,500. The following limits also apply.
    - 1,700 to 1,750 warheads attributed to deployed SLBMs;
    - Zero (0) warheads attributed to deployed ICBMs with more than one warhead; and
    - Zero (0) warheads attributed to deployed heavy ICBMs.
- In addition to reducing the number of deployed warheads, START II also eliminated heavy ICBMs and MIRV warheads on land-based ICBMs.
- While not done to comply with START II, the US unilaterally deactivated all MIRV'd LGM-118A Peacekeeper ICBMs by 2005 and converted all LGM-30G Minuteman III ICBMs to single re-entry vehicle per missile. Now, only Navy Trident SLBMs carry multiple warheads.

# Strategic Arms Reduction Treaty II

## (START II) (cont'd)

- START II, even though it never entered into force, was instrumental in reducing the Ohio-class SSBN fleet from 18 to 14 boats. Congressional Research Service report, *“Navy Trident Submarine Conversion (SSGN) Program: Background and Issues for Congress,”* dated 22 May 2008 offers the following rationale:
  - Anticipating that START II would enter into force, the Clinton Administration’s 1994 Nuclear Posture Review (NPR) recommended a strategic nuclear force that included 14 Trident SSBNs (all armed with D5 missiles) rather than 18.
  - Section 1302 of the FY1998 defense authorization act prohibited US strategic nuclear forces from being reduced during FY1998 below START I levels (including 18 Trident SSBNs) until the START II treaty entered into force. This prohibition was extended in FY1999 and made permanent in FY2000, but with a provision that permitted a reduction to 14 Trident SSBNs, even without START II entering into force, if the President certified to Congress that this reduction would not undermine the effectiveness of US strategic nuclear forces.
  - The Bush Administration’s 2002 NPR retained the idea of reducing the Trident SSBN force to 14 boats and converting 4 boats to SSGNs.
  - In FY2002, Congress provided funding for the SSGN conversion program to the level the Navy needed for a four-boat conversion program. The Bush Administration subsequently pursued the program as a four-boat effort.

# International Code of Conduct Against Ballistic Missile Proliferation

(Hague Code of Conduct, HCOC)

- Established on 25 November 2002; 138 member countries as of early 2018.
  - Not negotiated under the auspices of the United Nations.
  - Austria serves as the Immediate Central Contact (Executive Secretariat) and coordinates the information exchange of the HCOC.
  - India was the last nation to join on 1 June 2016.
- Calls for restraint and care in the proliferation of ballistic missile systems capable of delivering weapons of mass destruction.
  - It is the only normative instrument requiring pre-launch notifications and annual declarations from member states regarding their ballistic missile programs and space launch vehicle programs:
    - Annual outlines of their ballistic missile and space launch vehicle policies.
    - Annual information on the number and generic class of ballistic missiles and space launch vehicles launched during the preceding year
- Operates in parallel with Missile Technology Control Regime (MTCR).

# Strategic Offensive Reductions Treaty

(SORT, aka *Treaty of Moscow*)

- Signed by President G.W. Bush & Russian President Vladimir Putin on 24 May 2002 and ratified by the US Senate and Russian Duma.
  - EIF 1 Jun 2003
  - At that time, US and Russian nuclear arsenals each contained close to the 1991 START I limit of 6,000 “accountable” warheads apiece (which were counted using different counting rules than SORT, so this comparison is not precise).
- SORT Limits:
  - In a key departure from START I, SORT limited “operationally deployed” warheads, whereas START I limited warheads through declared attribution to their means of delivery (ICBMs, SLBMs, and heavy bombers).
  - Each Party agreed to reduce and limit strategic nuclear warheads so that by 31 December 2012 (the date SORT was scheduled to expire), the aggregate number operationally deployed warheads did not exceed 1,700 to 2,200 for each Party.
  - SSBNs being overhauled were assumed to not contain operationally deployed strategic nuclear warheads.
  - No warheads or delivery vehicle had to be destroyed under this accord.
    - “Spare” strategic warheads did not count against the treaty limit for operationally deployed warheads. The excess warheads were not required to be destroyed and could be placed in storage for later deployment.

# Strategic Offensive Reductions Treaty

(SORT, aka *Treaty of Moscow*) (cont'd)

- The US took the following actions to implement SORT:
  - US deactivated all 50 LGM-118A Peacekeeper ICBMs by 2005, each of which could be armed with 10 to 12 MIRV warheads (10 x Mk 21 or 12 x Mk 12A reentry vehicles).
  - The remaining US fleet of 450 LGM-30G Minuteman III ICBMs were converted from 3 x MIRV warheads to a single re-entry vehicle per missile.
  - The US permanently removed four Ohio-class submarines from SSBN service and converted them to tactical cruise missile submarines (SSGNs), leaving 14 SSBNs in the fleet.
  - The US SLBM fleet retained its MIRV warheads, but with fewer than the maximum number of re-entry vehicles per missile.
  - In 2006, the US fleet of 14 Ohio-class SSBNs started a cycle of three-year mid-life engineered refueling overhauls with up to two SSBNs out of service at any time up to about 2020. The SSBNs being overhauled have no operationally deployed warheads.
- SORT was superseded by New START on EIF date: 5 Feb 2011.



# Nuclear Posture Review

## NPR 2010

- Issued by the Obama administration.
- Not a treaty. This was a unilateral review by the US
- This NPR concluded that the US will, “retire the nuclear-equipped sea-launched cruise missile (TLAM-N).”
  - “This system serves a redundant purpose in the US nuclear stockpile. It has been one of a number of means to forward-deploy nuclear weapons in a time of crisis. Other means include forward deployment of bombers with either bombs or cruise missiles, as well as forward deployment of dual-capable fighters. In addition, US ICBMs and SLBMs are capable of striking any potential adversary. The deterrence and assurance roles of TLAM-N can be adequately substituted by these other means.....”
- The National Nuclear Security Administration’s (NNSA’s) Pantex Plant, near Amarillo, Texas, is charged with maintaining the safety, security and effectiveness of the nation’s nuclear weapons stockpile.
  - The B&W Pantex FY 2012 Performance Evaluation Summary, dated 23 October 2012, reported, “All W80-O warheads (formerly used on TLAM-N) in the stockpile have been dismantled.”
- Reference to TLAM-N is absent in SECNAVINST 8120.1A, dated 15 February 2013, “*Department of Navy Nuclear Weapons Responsibilities and Authorities.*”

# New START

- Formally known as *Measures for the Further Reduction and Limitation of Strategic Offensive Arms*.
  - Replaces START I and SORT
- Signed by President Barack Obama and Russian President Dmitry Medvedev on 8 April 2010.
  - EIF 5 Feb 2011
  - Expires in 10 years on 5 Feb 2021; may be extended for 5 years by mutual consent.
- The following limits are applicable to both sides commencing 5 Feb 2018 (seven years from the date the treaty entered into force):
  - Maximum of 700 deployed (operational) launchers, including ICBMs, SLBMs and nuclear-capable bombers.
  - Maximum of 800 deployed and non-deployed (nuclear capable) launchers.
  - 1,550 (or somewhat more\*) deployed strategic nuclear warheads.
    - Actual number of re-entry vehicles per missile are counted; one warhead per re-entry vehicle.
    - \* Only one warhead is counted per bomber regardless of how many warheads it actually carries. The actual number of free-fall nuclear bombs and/or air-launched cruise missiles can be much greater, 16 – 20 per bomber.
- Limits on total deployed + non-deployed launchers are intended to prevent each side from maintaining a stockpile of non-deployed launchers that could be made operational in a relatively short period of time.
- New START does not restrict the US or Russia from placing tactical nuclear nuclear-armed cruise missiles on submarines.

# Comparison of Treaty Limits

| Treaty                      | START (1991)  | Moscow Treaty (2002)  | New START (2010)  |
|-----------------------------|---|---|---|
| Limits on Delivery Vehicles | 1,600 strategic nuclear delivery vehicles   | No limits   | 800 deployed and nondeployed ICBM launchers, SLBM launchers and heavy bombers equipped to carry nuclear weapons<br><br>Within the 800 limit, 700 deployed ICBMs, SLBMs, and heavy bombers equipped to carry nuclear weapons |
| Limits on Warheads          | 6,000 warheads attributed to ICBMs, SLBMs, and heavy bombers<br><br>4,900 warheads attributed to ICBMs and SLBMs<br><br>1,100 warheads attributed to mobile ICBMs<br><br>1,540 warheads attributed to heavy ICBMs | 1,700-2,200 deployed strategic warheads<br><br>No sublimits | 1,550 deployed warheads<br><br>No sublimits   |
| Limits on Throwweight       | 3,600 metric tons   | No limit  | No limit  |

Source: The New START Treaty: Central Limits and Key Provisions, Congressional Research Service, February 2015

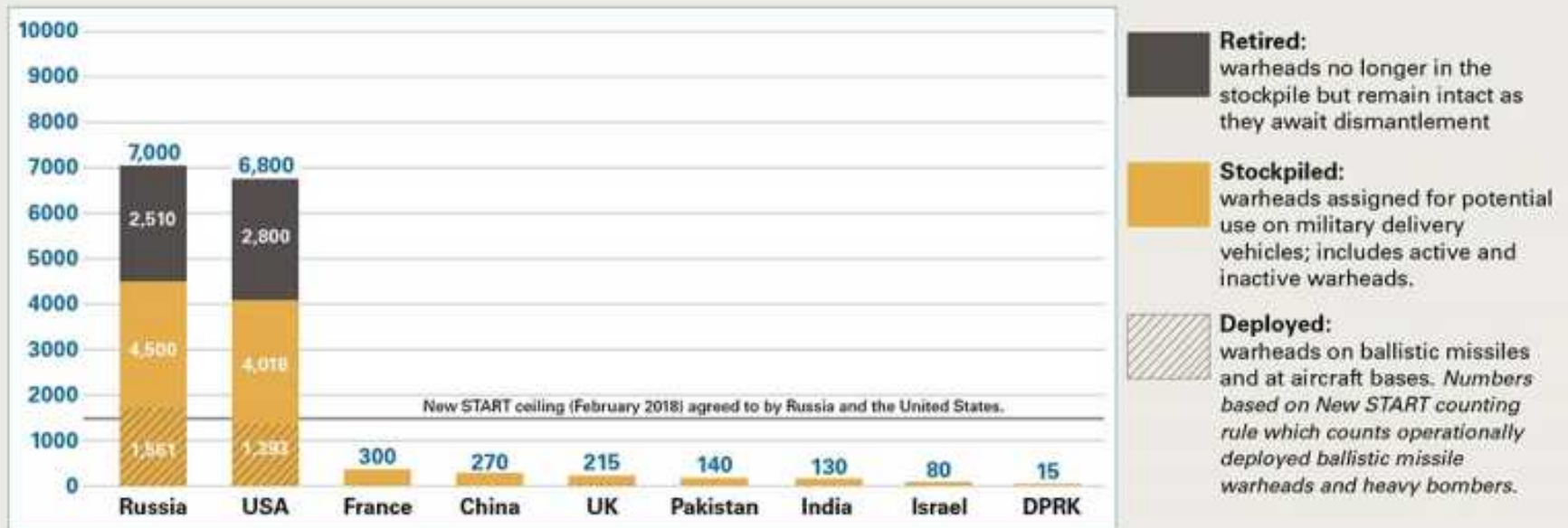
# New START implementation

- Each side has the flexibility to structure its nuclear forces as it wishes, within the limits of the treaty.
- 12 Jan 2018: The Department of State reported on the status of US compliance with limits on operational launchers and deployed warheads:
  - In 2015 the US Navy began reducing the number of operational missile tubes from 24 to 20 on the 14 remaining Ohio-class SSBNs. The US declared that it had:
    - 280 deployed and non-deployed SLBM launchers (launch tubes) in the Ohio-class SSBN fleet.
    - 212 deployed Trident II (D5) SLBMs.
    - 427 total inventory of deployed and non-deployed Trident II (D5) SLBMs.
  - The single-warhead Minuteman III ICBM fleet was reduced from 450 deployed launchers (missile silos) and missiles to 400.
- The treaty does not limit the number of operationally inactive stockpiled nuclear warheads. The Arms Control Association estimated that, as of 2 January 2018, the US and Russia had the following inventories.
  - US: 6,800 total warheads; 1,393 deployed, 4,018 in the active and inactive stockpile, 2,800 retired but not yet dismantled
  - Russia: 7,000 total warheads; 1,561 deployed, 4,500 in the active and inactive stockpile, 2,510 retired but not yet dismantled

# Current compliance with New START limits

## 2017 Estimated Global Nuclear Warhead Inventories

The world's nuclear-armed states possess a combined total of roughly 15,000 nuclear warheads; more than 90 percent belong to Russia and the United States. Approximately 9,600 warheads are in military service, with the rest awaiting dismantlement.



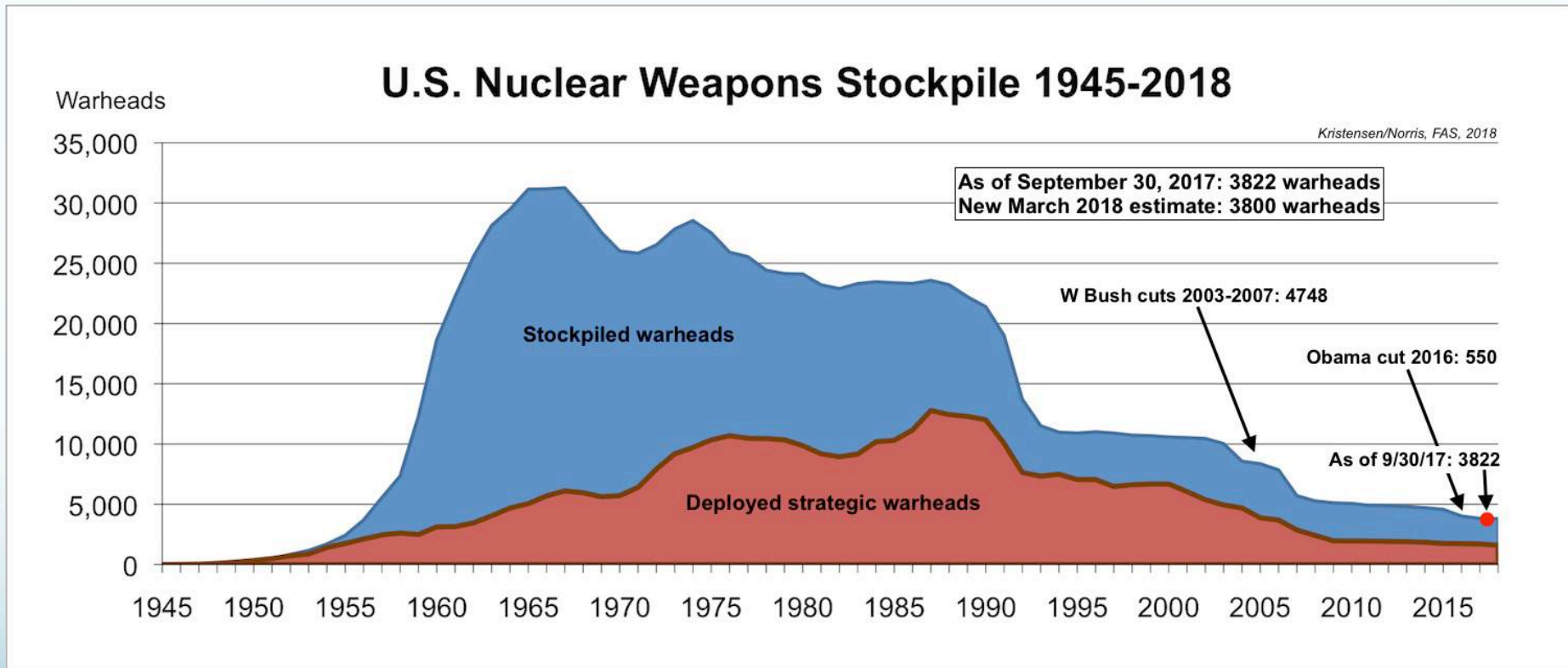
Sources: Hans M. Kristensen and Robert S. Norris; U.S. Department of State, Updated January 2, 2018.

ArmsControl  
Association

Source: Arms Control Association, "Nuclear Weapons: Who Has What at a Glance," January 2018



# US nuclear weapons stockpile 1945 - 2018



Source: FAS, Kristensen/Norris, <https://fas.org/wp-content/uploads/2018/03/Stockpile-History.jpg>



# New START and Conventional Prompt Global Strike (CPGS)

- New START does not prohibit either side from deploying conventional warheads on strategic ballistic missiles.
  - These strategic missiles would be counted against the treaty limits.
  - The treaty cautions that both sides should be, “mindful of the impact of conventionally-armed IRBMs and SLBMs on strategic stability.”
  - The “strategic stability” issue with such weapons arises from the fact that the target nation may not be able to determine if the weapon carried a conventional or nuclear warhead. Their reaction could be an unintended escalation to a nuclear conflict.
- The US Navy and Air Force are planning weapons called Conventional Prompt Global Strike (CPGS), which are intended to deliver a precision conventional warhead to strike any point in the world within 1 hour of launch.
  - In 2008, Congress rejected a Navy proposal to arm a small number of Trident II (D5) SLBMs with conventional warheads for use on CPGS missions. However, Congress created a single, combined fund to support research and development for the CPGS mission.
  - In February 2014, the Navy solicited bids for a 2-year industry trade study for a submarine-launched, intermediate-range, hypersonic, CPGS weapon.
  - In October 2017, the Navy Strategic Systems Program (SSP) flew from the Pacific Missile Range Facility in Hawaii the first conventional prompt strike missile for the United States Navy, in the form factor that could eventually be utilized in an Ohio-class missile tube and one day be deployed on guided-missile submarines (SSGNs) rather than SSBNs.

# Nuclear Posture Review

## Draft NPR 2018

- January 2018 draft prepared by the Trump administration.
- Not a treaty. This was a unilateral action by the US
- Key points related to the US nuclear submarine force included:
  - Recapitalizing the US nuclear weapons complex is long past due; it is vital to ensure the capability to design, produce, assess and maintain nuclear weapons for as long as they are required.
  - Russia, China and North Korea have undertaken significant nuclear modernization and introduced new threats since 2010, including Russia's Borei-class SSBN, Status-6 (Kanyon) nuclear-armed strategic torpedo, and a new SLBM and SLCM.
  - Restoring the nuclear-armed, submarine-launched cruise missile (SLCM) capability is necessary. This capability was retired by NPR 2010.
  - A small number of existing SLBM warheads to provide a low-yield option.
  - The Navy will begin studies in 2020 on an SLBM that will replace the aging Trident II (D5) and be deployed throughout the service life of the new Columbia-class SSBN.
- The draft NPR 2018 did not indicate whether the US might seek a five-year extension of the New START treaty, which is scheduled to expire on 5 February 2021. However, draft NPR 2018 indicated that the US was unlikely to negotiate a new treaty before the New START expiration.

# Fissile Material Cutoff Treaty

## (FMCT)

- FMCT is a proposed international treaty intended to prohibit the production of highly-enriched uranium (HEU) and weapons-grade plutonium.
  - HEU = enrichment  $> 20\%$
  - LEU = enrichment  $\leq 20\%$
- Preliminary FMCT discussions have been held by the UN Conference on Disarmament (CD), which is a body of 65 member nations established as the sole multilateral negotiating forum on disarmament.
  - Nations that joined the NPT as non-weapon states already are prohibited from producing or acquiring fissile material for weapons.
  - The Arms Control Association reported in 2017: “In order for negotiations to begin on an FMCT, Pakistan will have to remove its opposition vote, and a consensus to move forward with negotiations must be reached. Pakistan has been primarily concerned that an FMCT would lock them into a disadvantageous position relative to India’s superior nuclear stockpile. Consequently, Islamabad would like an FMCT to include current fissile material stockpiles, instead of just capping future production, a position shared by several other countries.”

# Fissile Material Cutoff Treaty

## (FMCT) (cont'd)

- As of January 2017, the International Panel on Fissile Material (IPFM) reported that the global stockpile of HEU was estimated to be about 1,340 ± 125 tons.
- IPFM estimated that the global stockpile of separated plutonium was about 520 tons, of which about 290 tons is in civilian custody.

### Fissile Material Production End Dates

| Country     | Highly-enriched Uranium HEU                                      | Weapons-grade Plutonium      |
|-------------|--|------------------------------|
| USA         | Stopped in 1992 (since 1964 for naval fuel only)                 | Stopped in 1987              |
| Russia      | Stopped in 1987-88; IPFM reported restart at Zelenogorsk in 2012 | Stopped in 1994              |
| UK          | Stopped in 1963 (imports from USA)                               | Stopped in 1989              |
| France      | Stopped in 1996  | Stopped in 1992              |
| China       | Stopped in 1987-89 (unofficial)                                  | Stopped in 1990 (unofficial) |
| India       | Ongoing  | Ongoing                      |
| Pakistan    | Ongoing  | Ongoing                      |
| Israel      | Status unknown   | Ongoing                      |
| North Korea | Status unknown   | Ongoing                      |
| Brazil      | Claims not to enrich >20%  | None                         |

Source: adapted from 18 Sep 2017, Arms Control Association, <https://www.armscontrol.org/factsheets/fmct>

# Fissile Material Cutoff Treaty

## (FMCT)

- If FMCT is ever passed, it would put at risk the continued use of HEU as naval reactor fuel.
  - Large HEU inventories exist in the US, Russia and UK
  - Long operating lives of modern HEU-fueled naval reactors (i.e., 30 to 42 years) will make their phase-out difficult to justify before the normal end of their operating life.

# Marine reactor fuel enrichments in use in nuclear fleets

- U.S and UK:
  - The US Navy is known to operate reactor cores fueled by very highly enriched uranium, either 97% produced specifically for naval reactors, or 93% extracted from surplus nuclear weapons.
  - UK naval reactor fuel is believed to use the same enrichment. UK has imported some HEU for naval fuel from the US
- Russia:
  - Russian naval reactors typically use HEU fuel. For example, the most commonly used submarine reactor, the OK-650, uses a fuel enrichment of 20 – 45%.
  - Russia's older-generation Arktika-class icebreakers with OK-900A reactors use HEU fuel enriched to 55 - 90%.
  - Russia's *Sevmorput* ice-breaking cargo ship and the Taimyr-class icebreakers respectively have KLT-40 and KLT-40M nuclear power plants that operate on HEU fuel enriched to 30 – 40%.
  - Russian new civilian marine reactors for the LK-60-class icebreakers (RITM-200 PWR) and a floating nuclear power plant (KLT-40S PWR) are designed to operate with LEU fuel.



# Marine reactor fuel enrichments in use in nuclear fleets (cont'd)

- France:
  - Except for their 1<sup>st</sup>-generation PWR/SNLE PWRs, which have been retired, all operating French naval reactors have been designed to operate with LEU fuel.
  - The newest reactor for the Barracuda SSN is believed to be designed to operate with the same LEU enrichment as commercial nuclear power plants (typically about 3.5%).
- China
  - Chinese naval reactors have been reported to operate with LEU fuel enriched to about 5%.
- India:
  - India's PWR naval reactor prototype operates with 30% enriched HEU fuel.
  - The fuel enrichment for India's first nuclear submarine, *Arihant*, is not known.
- Brazil:
  - Brazil claims its future 2131-R PWR naval reactor will use LEU fuel.

# Prospects for 2018 - 2030

# Prospects for 2018 - 2030

- **The number of nuclear marine nations will increase.**
  - Brazil is expected to start construction of its indigenous nuclear-powered attack submarine (the SN-BR) by about 2020 and deliver the sub by 2030.
    - Brazil's continuing poor economic condition has delayed the PROSUB project to build four indigenous conventional submarines (SBRs) and the SN-BR.
    - When complete, the fleet of four SBRs and the SN-BR will give Brazil's Navy the capability to more effectively patrol that nation's 7,491 km (4,655 mi) coastline and protect national interests in the exclusive economic zone (EEZ).
  - No additional nations are expected to develop their own nuclear submarine or surface vessel within the next decade.
    - Iran, Pakistan and North Korea may have the political aspirations to develop a global reach, but are unlikely to be capable of deploying an indigenous nuclear submarine in the next decade without substantial technical assistance from an outside source, or a lease of a nuclear submarine from Russia or China.

# Prospects for 2018 - 2030

- **The number of nuclear marine nations will increase. (cont'd)**
  - Based on the precedent of leasing SSNs to India, the possibility exists that Russia will lease a nuclear submarine to one or more other nations that previously had no nuclear fleet.
  - Successful demonstration later this decade of the Russian floating nuclear power plant, *Akademik Lomonosov*, or a similar Chinese floating nuclear power plant also being developed, could lead to international orders from other nations for floating nuclear power plants.

# Prospects for 2018 - 2030

- **The number of nuclear marine vessels in the worldwide fleet likely will increase by 17 – 20 vessels, to a total of 192-195 vessels, by 2030.**
  - The worldwide fleet of operating nuclear-powered vessels as of mid-2018 stands at a total of 175 vessels.
  - Growth is driven primarily by the newer nuclear marine nations (China, India, Brazil).
  - The older nuclear marine nations (US, Russia, UK & France) will be making major investments to replace or extend the operating lives of aging nuclear submarine and surface ship fleets. Being able to replace the older vessels, even on a one-for-one basis, will be a significant economic challenge for these nations.
  - The US nuclear fleet will be smaller in 2030.
    - The Navy SSN fleet is expected to decrease to about 41 SSNs by 2028. All Ohio-class SSGNs will have been retired, as well as the first few Ohio-class SSBNs. The new Columbia-class SSBNs will not start entering the fleet until about 2031.
    - The Navy will attempt to hold the carrier fleet level steady at 11 while starting retirement of Nimitz-class carriers in 2024.
    - US nuclear fleet size is expected to decline by about 15 subs to a total of 68 vessels by 2030.

# Prospects for 2018 - 2030

- **The number of nuclear marine vessels in the worldwide fleet likely will increase by 17 – 20 vessels, to a total of 190-193 vessels, by 2030. (cont'd)**
  - The Russian fleet will start growing back slowly after two decades of under-funding.
    - All existing Delta-III and Delta-IV SSBNs likely will be retired by 2030 (the youngest Delta-III still in the fleet was commissioned in 1982 and the youngest Delta-IV in 1990).
    - Even with the ongoing modernization of existing Sierra and Akula SSNs and Oscar SSGNs, these subs will be approaching the end of their service life by 2030.
    - New-build programs for the multi-purpose Yasen-M and Husky SSNs and Borei II SSBNs will have difficulty just keeping up with the rate of retirement of the older subs.
    - New-build LK-60 nuclear icebreakers will allow retirement of the older generation of nuclear icebreakers. Other new-build nuclear icebreakers to be introduced in the mid-2020s will slightly expand the size of nuclear icebreaker fleet.
    - Modernization of one Kirov-class CGNs should be completed by 2020, complemented by new-construction Leader-class nuclear-powered destroyers that are expected to start entering the fleet in the mid-2020s. This will expand the Russian Navy's nuclear surface fleet by 2030.
    - Deployment of *Akademik Lomonosov* in this decade likely will be followed by additional floating nuclear power plants in remote Arctic ports by 2030.
    - Russian nuclear fleet size could grow by 2 - 5 vessels to a total of 59 – 62 by 2030.



# Prospects for 2018 - 2030

- **The number of nuclear marine vessels in the worldwide fleet likely will increase by 17 – 20 vessels, to a total of 190-193 vessels, by 2030. (cont'd)**
  - The UK nuclear submarine fleet size may remain constant.
    - Astute-class SSNs are intended to replace Trafalger-class SSNs on a 1-for-1 basis.
      - Earlier-than-planned retirement of Trafalger-class SSNs could occur following discovery in 2016 of a significant weld fracture problem in nuclear system piping. Worst case: all four boats retire, leaving the UK with a significant shortfall in SSNs.
    - Dreadnought-class SSBNs will replace Vanguard-class SSBNs on a 1-for-1 basis starting in the 2030s.
    - The number of SLBMs and warheads in the SSBN fleet will continue to decrease as a result of the UK's 2015 Strategic Defense and Security Review (SDSR).
  - The French nuclear vessel fleet size will be constant.
    - Barracuda-class SSNs will replace aging Rubis-class SSNs on a 1-for-1 basis.
    - Le Triomphant-class SSBNs will remain operational beyond 2030, but a program to develop the replacement SSBN will have to start in the early 2020s.
    - In early 2017, aircraft carrier *Charles de Gaulle* entered a 2-year mid-life overhaul that is expected to allow the ship to continue operating for 20 more years, at least until 2039.

# Prospects for 2018 - 2030

- **The number of nuclear marine vessels in the worldwide fleet likely will increase by 17 – 20 vessels, to a total of 190-193 vessels, by 2030. (cont'd)**
  - China's nuclear vessel fleet size will grow:
    - Improved Type 93 and multi-mission Type 95 SSNs will be added to the fleet.
    - Type 94 and new Type 96 SSBNs will be added to the fleet.
    - Next-generation subs will be under construction before 2020s.
    - The earliest Type 91 SSNs and the one Type 92 SSBN will be retired by 2030.
    - The intent to build a nuclear powered aircraft carrier (CVN) has been raised by China.
      - China has limited experience building and operating aircraft carriers. Their first aircraft carrier is a Soviet-era design purchased from Ukraine and modernized in China. *Liaoning* was launched in 2011.
      - In April 2017, China launched its first indigenous, conventionally-powered aircraft carrier.
      - Deployment of a nuclear-powered aircraft carrier within the next decade is unlikely because of the long lead time to design and construct a CVN with its rather large nuclear power plant.
  - China could add 20 or more nuclear submarines to its fleet by 2030 (at a new-build rate of about two per year minus a few retirements).

# Prospects for 2018 - 2030

- **The number of nuclear marine vessels in the worldwide fleet likely will increase by 17 – 20 vessels, to a total of 190-193 vessels, by 2030. (cont'd)**
  - India's nuclear fleet will grow:
    - India will continue construction of its indigenous SSBN fleet to strengthen its national nuclear deterrent force.
    - India may lease additional SSNs from Russia, perhaps even a current-generation Yasen-class SSN.
    - In 2015, India initiated development of an indigenous SSN, with plans for construction of six such submarines.
    - By 2030, India could add seven or more nuclear submarines to its fleet (at an assumed rate of one per two years).
  - Brazil will have one or more indigenous SSNs by 2030.
    - Current plans are for the first SSN to enter the fleet in 2023.
    - 2010 Joint Plan for Marine Equipment of Brazil calls for six SSNs by 2034.
    - By 2030, Brazil could have three or more indigenous SSNs (at an assumed rate of one per three years), but this will be highly dependent on the state of Brazil's currently-weak economy.
  - Worldwide nuclear fleet will have a net growth of 17 - 20 vessels by 2030.

# Prospects for 2018 - 2030

- **The ability to operate underwater at high speed for long durations no longer is the sole domain of the nuclear-powered submarine.**
  - Nuclear submarines and naval surface forces will be increasingly challenged by the latest generation of non-nuclear submarines using various types of advanced diesel-electric or air-independent propulsion (AIP) systems.
  - A well-equipped modern “conventional” submarine has the ability to operate effectively, and silently, at relatively long range against all adversary forces.
    - The availability of such “conventional” submarines will provide a much lower-cost alternative to nations that do not wish to make the substantial investment in nuclear infrastructure needed to sustain a fleet of nuclear-powered submarines.
  - Armament of these modern conventional submarines is comparable to SSNs and SSGNs operated by the US and Russia.

# Prospects for 2018 - 2030

- **The “attack submarine” has evolved into a multi-purpose platform capable of a wide variety of missions.**
  - The newest generation of SSNs has blurred the distinction between SSNs and SSGNs by carrying a large arsenal of missiles in vertical launch system (VLS) tubes while retaining SSN weaponry in the traditional torpedo room. Examples are:
    - US Virginia-class Block V to VII SSNs
    - Russian Yasen / Yasen-M-class SSNs and the planned Husky-class SSNs
    - Chinese improved Type 93G SSNs
  - The ability for submarines to host, deploy and recover special operations forces (SOF) and their equipment has become commonplace.
  - The use of unmanned underwater vehicles (UUV) and encapsulated unmanned aerial systems (UAS) launched from submarines is rapidly increasing.

# Prospects for 2018 - 2030

- **Use of unmanned underwater vehicles (UUV) and unmanned aerial systems (UAS) will be “force multipliers.”**
  - UUVs and UASs will greatly expand the capabilities of vessels equipped to use them.
  - As the US SSN fleet continues to decline in size over the next decade, the availability of such force multipliers will be particularly important for maintaining or expanding SSN operational capabilities.
  - However, UUVs and UASs can be adopted by all navies, on conventional or nuclear vessels. The net result will be a much more complex operating environment for naval fleets.



# Prospects for 2018 - 2030

- **Many nations now have the capability to raise a significant anti-access/area denial (A2/AD) challenge to US nuclear-powered aircraft carriers and their carrier strike groups, or to any other surface fleet.**
  - Examples of A2/AD weaponry include:
    - Chinese DF-21D anti-ship ballistic missiles with a range of 900 miles (1,448 km)
    - Long-range, high-speed, anti-ship cruise missiles, like India's Brahmos Mach 3 cruise missile with a range of 180 mi (290 km), or Russia's similar P-800 Oniks.
  - Some individual submarines and surface ships can salvo-launch a very large quantity of cruise missiles that may be able to overwhelm the defense capabilities of a carrier strike group.
    - Russian Oscar SSGNs currently carry 24 x P-700 Granit (SS-N-19) and soon will be modified to carry 72 x P-800 (SS-N-26) Oniks.
    - Russian Yasen SSN can carry 24 x P-800 Oniks, or a larger number of smaller missiles.
  - The combat role of an aircraft carrier strike group will likely evolve to either deal with or avoid the growing A2/AD threat.

# Prospects for 2018 - 2030

- **Prospects for new commercial nuclear marine propulsion applications remain uncertain.**
  - Other than new nuclear powered icebreakers (Russia) and floating nuclear power plants (Russia and China), it is unlikely that any nation or firm will develop and license a nuclear-powered commercial vessel before 2030.
  - Lloyd's Register updated its 'rules' for nuclear ships, which concern the integration of a reactor certified by a land-based regulator with the rest of the ship.
    - Lloyd's claims this was done in response to its members' interest in commercial marine nuclear propulsion.
    - Interest was driven primarily by market-based measures for controlling carbon dioxide emissions from maritime operations.

# Prospects for 2018 - 2030

- **Prospects for new commercial nuclear marine propulsion applications remain uncertain. (cont'd)**
  - Practical considerations may limit the primary market for new commercial nuclear-powered ships to point-to-point heavy cargo ships, or single port heavy tugs.
    - These applications minimize the number of different national nuclear regulatory organizations that need to be involved in licensing and providing nuclear safety / operational oversight of commercial nuclear marine activities.
    - It also minimizes the investment in nuclear power port infrastructure and emergency preparedness infrastructure needed to support a commercial nuclear vessel.
      - Few nations have the in-place regulatory and nuclear service infrastructure needed to support the operation of a commercial nuclear-powered vessel.
      - Developing and licensing the physical and administrative infrastructure at the ports of interest could take a decade or more and require significant investment.

# Prospects for 2018 - 2030

- **The role of nuclear vessels in the Arctic will increase, and most of them will be Russian vessels.**
  - Russia's nuclear-powered polar icebreaker fleet and soon-to-be-deployed floating nuclear power plant give that nation unmatched capabilities to explore and commercialize the Arctic by:
    - Establishing reliable open sea lanes for other vessels in ice-covered regions along the Northern Sea Route.
    - Enabling the exploration for, and exploitation of, petroleum, mineral and natural resources along the Russian Arctic coast and in off-shore waters.
  - If Russia's 2015 Extended Continental Shelf (ECS) claim is upheld by the Commission on the Limits of the Continental Shelf, Russia will have the resources and the means to enforce its expanded exclusive economic zone (EEZ).
    - No other Arctic nation has comparable means to operate in the Arctic region with nuclear- and conventionally-powered Arctic-capable civilian and military vessels.
    - The general decline of the US and Canadian conventional icebreaker fleets opens great opportunities for Russia to dominate the Arctic region.

# Prospects for 2018 - 2030

- **The role of nuclear vessels in the Arctic will increase, and most of them will be Russian vessels. (cont'd)**
  - Nuclear submarines will continue to have greater freedom of navigation in the Arctic than any other class of vessel.
    - Russia's large number of small, deep-diving, nuclear-powered submarines and associated "motherships" gives them unique capabilities for underwater exploration and other activities in the Arctic and worldwide.
- **Progress will be made in cleaning up radioactive contamination in the Arctic.**
  - Continued political pressure, plus economic incentives related to Arctic resource development in the region, will encourage Russia to remediate some nuclear waste sites and sunken nuclear submarine sites in the Kara Sea and the Barents Sea.
  - International efforts will remove the last Russian Radioisotope Thermoelectric Generators (RTGs) from the Arctic.

# Prospects for 2018 - 2030

- **Retired nuclear naval vessel decontamination and final processing (storage of some parts, scrapping of other parts) will remain an ongoing issue that seems to be improving:**
  - New facilities near Vladivostok, in the Russian Far East, will enable more effective decontamination and final processing of retired Pacific Fleet nuclear vessels and will provide for storage of sealed reactor compartments on land.
  - The US Navy's Nuclear Ship & Submarine Recycling Program (NSSRP) will be challenged by the scale and complexity of work to process retired nuclear aircraft carriers.
  - US is modernizing its Expended Core Facility in Idaho, and will be moving all naval spent fuel into dry storage.
  - The UK must resolve the current nuclear regulatory impasse that is preventing the de-fueling of some retired subs and the decontamination and scrapping of others that have been de-fueled.
  - China will need to implement decontamination and decommissioning processing of their first retired nuclear submarines.



# Prospects for 2018 - 2030

- **Increasing international pressure for a Fissile Material Cutoff Treaty (FMCT) could have an impact in the long-term on use of HEU in naval reactors.**
  - Only the US and the UK continue to use HEU enriched to  $\geq 93\%$  U-235, and would be most impacted by an FMCT.
  - Without a Congressional requirement to transition to LEU fuel, and provision of the associated funding to enable the broad scope of work needed for such a transition, it is highly unlikely that Naval Reactors would independently undertake such a project.
- **Other matters:**
  - Retired US nuclear merchant ship *NS Savannah*, which currently is docked in Baltimore harbor, hopefully will get funding for final cleanup and conversion to a museum ship.
  - Retired Russian nuclear icebreaker *Arktika* is expected to become a museum ship in St. Petersburg.
  - Retired UK SSN *Dreadnought* (S101) may become a museum ship in Barrow-on-Furness.